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J. J. Davis Associates, McLean, Va.

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16. ABSTRACT The manual provides an introduction to physical coal cleaning to individuals outside of the coal preparation industry. Specifically, the manual covers the general nature and characteristics of U.S. coals, provides an overview of the coal preparation plant, discusses the major equipment and processes currently in use in coal preparation, identifies the primary waste streams found during the coal cleaning operation, discusses the techniques of control currently applied to those waste streams, and describes the contaminant removal potential of coal.

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by

David C. Nunenkamp

J. J. Davis Associates
7900 Westpark Drive
McLean, Virginia 22101

Contract No. 68-02-1834
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EPA Project Officer: Mark J. Stutsman

Industrial Environmental Research Laboratory
Office of Energy, Minerals, and Industry
Research Triangle Park, NC 27711

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TABLE OF CONTENTS
COAL PREPARATION ENVIRONMENTAL
ENGINEERING MANUAL

CHAPTER **PAGE**

1 INTRODUCTION 1
- 1.1 Backgrcund 1
- 1.2 Purpose 5
- 1.3 Organization 5

2 THE NATURE OF COAL 9
- 2.1 Coal and Its Origin 9
- 2.2 Properties of Coal 15
  - 2.2.1 Specific Gravity 17
  - 2.2.2 Size Stability and Uniformity 18
    - 2.2.2.1 Friability 19
    - 2.2.2.2 Weathering 19
  - 2.2.3 Grindability 20
  - 2.2.4 Impurities in Coal 21
    - 2.2.4.1 Moisture 21
    - 2.2.4.2 Minerals 22
      - 2.2.4.2.1 Clay and Shale 24
      - 2.2.4.2.2 Sulfur 26
- 2.3 Coal Reserves 28

3 OBJECTIVES OF COAL PREPARATION 41
- 3.1 Background 41
- 3.2 Current Practice 42
- 3.3 Metallurgical Coke 44

TABLE OF CONTENTS
(Continued)

CHAPTER PAGE

OBJECTIVES OF COAL PREPARATION (Continued)

3.4 Steam Coal 45

3.5 Summary 48

4 THE PREPARATION PROCESS 53

4.1 Overview 53

4.2 Preparation Plant Modules 60

5 PLANT FEED PREPARATION AND RAW COAL STORAGE 69

5.1 Overview 69

5.2 Initial Size Check 69

5.2.1 Fixed ROM Coal Screen 72

5.2.2 Vibrating ROM Coal Screen 72

5.3 Initial Size Reduction 75

5.3.1 Rotary Breaker 78

5.3.2 Other ROM Coal Crushers 80

5.4 Raw Coal Storage 83

5.4.1 Open Storage for Raw Coal 86

5.4.2 Closed Storage for Raw Coal 88

5.4.2.1 Steel Storage Bins 88

5.4.2.2 Concrete Silos 89

6 RAW COAL SIZING 95

6.1 Overview 95

6.2 Notes on Screening 97

6.3 Application 107

6.3.1 The Raw Coal Screen 107

6.3.2 Pre-Wetting Screens 109

7 RAW COAL SEPARATION 115

7.1 Overview 115

7.2 Specific Gravity Separation 117

TABLE OF CONTENTS
(Continued)

CHAPTER PAGE

RAW COAL SEPARATION (Continued)

7.3 Methodologies 121

7.3.1 Dense Medium Separation of Coarse Coal 121

7.3.1.1 Magnetite Dense Media Coal Cleaning 124

7.3.1.2 Sand Cone Dense Media Coal Cleaning 136

7.3.2 Dense Media Coarse Size Coal Washing Equipment 141

7.3.3 Hydraulic Separation of Coarse Coal 152

7.3.4 Hydraulic Coarse Coal Cleaning Equipment 161

7.3.5 Separation of Intermediate Size Coal 170

7.3.5.1 Dense Media Cyclones 171

7.3.5.2 Hydrocyclones 176

7.3.5.3 Wet Concentrating Tables 181

7.3.5.4 Fine Coal Launders and Jigs 181

7.3.6 Separation of Fine Size Coal 190

8 PRODUCT DEWATERING AND DRYING 209

8.1 Overview 209

8.2 Methodology 210

8.2.1 Natural Drainage 210

8.2.2 Screens 212

8.2.2.1 Special Purpose Screens for the Heaving Media Process 216

8.2.2.2 Special Purpose Combination Screens (Intermediate and Fine) 221

8.2.2.3 Special Purpose Solid Recovery Screens 222

8.2.2.4 Special Purpose Fixed Screens 227

8.2.3 Centrifugal Dewatering 233

8.2.4 Filtration 242

TABLE OF CONTENTS
(Continued)

CHAPTER		PAGE
	PRODUCT DEWATERING AND DRYING (Continued)	
	8.2.5 Thermal Drying	249
	8.3 Thickening Coal and Refuse Slurries	255
	8.3.1 Hydraulic Cyclones	257
	8.3.2 Classifiers	260
9	CLEAN COAL STORAGE AND HANDLING	275
	9.1 Overview	275
	9.2 Clean Coal Sotrage	278
	9.2.1 Open Storage for Clean Coal	280
	9.2.2 Closed Storage for Clean Coal	285
	9.3 Clean Coal Handling	287
	9.3.1 Unit Train Loading	288
	9.3.2 Barge Loading	293
	9.3.3 Slurry Pipeline	297
10	REFUSE HANDLING	301
	10.1 Overview	301
	10.2 Materials Handling	302
	10.2.1 Refuse Handling by Aerial Tramway	303
	10.2.2 Refuse Handling by Belt Conveyor	303
	10.2.3 Vehicular Haulage Units	305
11	THE COMPLETE PREPARATION PLANT	313
	11.1 Overview	313
	11.2 The Complete Plant	314
	11.2.1 The Coarse Size Coal Circuit	316
	11.2.2 The Intermediate Size Coal Cleaning Circuit	320
	11.2.3 The Fine Size Coal Cleaning Circuit	323
	11.2.4 The Refuse Recovery Circuit	327
	11.2.5 Process Quantities	329
	11.3 The Economics and Management of Coal Preparation	331

TABLE OF CONTENTS
(Continued)

CHAPTER **PAGE**

THE COMPLETE PREPARATION PLANT (Continued)

11.3.1 Defining Properties of Raw Coal 335

11.3.2 Washability Studies 338

11.3.3 Determining Economical Washing Specific Gravities 339

11.3.4 Selection of the Process Flowsheet 342

12 POTENTIAL POLLUTANTS 349

12.1 Introduction 349

12.2 Identification of Potential Pollutants 350

12.2.1 Solid Refuse 350

12.2.2 Mine Site and Waste Dump Drainage 356

12.2.3 Air Contaminants 364

12.2.3.1 Aerosols or Particulate Matter 365

12.2.3.2 Inorganic Gases 368

12.2.4 Noise 371

13 CONTROL OF POTENTIAL POLLUTANTS 391

13.1 Introduction 391

13.2 Refuse Disposal and Pollution Control Technology 391

13.2.1 Refuse Disposal Versus Constructed Embankments 398

13.2.2 Refuse Disposal Site Selection Criteria 404

13.2.2.1 Hydrologic Investigations 407

13.2.2.1.1 Seepage and Pore Pressure 413

13.2.2.2 Stability Analysis 419

13.2.2.3 Physical Properties of Coarse Coal Refuse 420

13.2.2.3.1 Grain Size Distribution 421

TABLE OF CONTENTS
(Continued)

CHAPTER **PAGE**

CONTROL OF POTENTIAL POLLUTANTS (Continued)

13.2.2.3.2 Atterberg Limits 427

13.2.2.3.3 Specific Gravity 427

13.2.2.3.4 Natural Water Content and Dry Density 427

13.2.2.3.5 Compaction Characteristics 429

13.2.2.3.6 Permeability 432

13.2.2.3.7 Compressiblity 434

13.2.2.3.8 Shear Strength 434

13.2.2.4 Physical Properties of Fine Coal Refuse 437

13.2.2.4.1 Grain Size Distribution 438

13.2.2.4.2 Plasticity Characteristics 438

13.2.2.4.3 Specific Gravity 438

13.2.2.4.4 Natural Water Content and Dry Density 438

13.2.2.4.5 Compaction 441

13.2.2.4.6 Permeability 444

13.2.2.4.7 Compressibility 445

13.2.2.4.8 Shear Strength 446

13.2.2.5 Conclusions Regarding Physical Properties of Coal Refuse Materials 449

13.2.2.5.1 Unique Characteristics of Coal Refuse 451

13.2.2.5.2 Conveyance and Placement 452

13.2.3 Types of Refuse Deposits 454

13.2.3.1 Ridge Dump 454

13.2.3.2 Side-Hill Dump 456

13.2.3.3 Cross-Valley Dump 456

TABLE OF CONTENTS
(Continued)

CHAPTER | PAGE

CONTROL OF POTENTIAL POLLUTANTS (Continued)

- 13.2.3.4 Valley Fill Dump 457
- 13.2.3.5 Waste Heap 457
- 13.2.3.6 Complex Dump 457
- 13.2.4 Construction Techniques Proposed for Consideration 458
  - 13.2.4.1 Modification of Existing Deposits 459
    - 13.2.4.1.1 Active Deposits 459
    - 13.2.4.1.2 Inactive Deposits 460
    - 13.2.4.1.3 Abandoned Deposits 460
  - 13.2.4.2 Proposed Deposits 461
- 13.2.5 Types of Refuse Impoundments 462
  - 13.2.5.1 Cross-Valley Impoundments 463
  - 13.2.5.2 Side-Hill Impoundments 465
  - 13.2.5.3 Diked Pond 465
  - 13.2.5.4 Incised Pond 466
- 13.2.6 Construction Techniques 466
- 13.2.7 Surveillance, Maintenance and Abandonment 471
  - 13.2.7.1 Surveillance 473
  - 13.2.7.2 Embarkment Surveillance and Instrumentation 476
    - 13.2.7.2.1 Surface Monuments 477
    - 13.2.7.2.2 Piezometers 478
    - 13.2.7.2.3 Internal Movement Devices 479
  - 13.2.7.3 Maintenance 480
  - 13.2.7.4 Abandonment 481
- 13.2.8 Embankment Construction Inspection 483
  - 13.2.8.1 Requirements of Plans and Specifications 485
  - 13.2.8.2 Verifications of Design Assumptions 485

TABLE OF CONTENTS
(Continued)

CHAPTER PAGE

CONTROL OF POTENTIAL POLLUTANTS (Continued)

13.2.8.3 Site Inspector's Functions 486

13.2.8.4 Regulatory Agency 488

13.2.8.4.1 If Method Specifications are Used 490

13.2.8.4.2 If Performance Specifications are Used 491

13.2.8.5 Documentation of Inspection Control Results 492

13.2.9 Embankment and Impoundment Recognition Summary 493

13.2.9.1 Conditions Affecting Stability 493

13.2.9.1.1 Loading Area 494

13.2.9.1.2 Toe Area 494

13.2.9.1.3 Materials Area 495

13.2.9.1.4 Foundation Area 496

13.2.9.2 Forms of Instability 497

13.2.9.2.1 Rotational Slips 497

13.2.9.2.2 Surface Slips 497

13.2.9.2.3 Flow-Type Slides 497

13.2.9.2.4 Creep 498

13.2.4.2.5 Back-Sapping 498

13.2.9.3 Factors Affecting Stability 499

13.2.9.3.1 Appearance of the Site 500

13.2.9.3.2 General Embankment Characteristics 501

13.2.9.3.3 Slude Disposal Considerations 502

13.2.9.3.4 Water as It Relates to Embankment Stability 502

13.2.9.3.5 Water as It Relates to Flooding 503

13.2.9.4 Hazards Rating System 504

TABLE OF CONTENTS
(Continued)

CHAPTER PAGE

CONTROL OF POTENTIAL POLLUTANTS (Continued)

13.2.10 Control of Mine Drainage from Coal Refuse Deposits 507

13.2.11 Closed Water Circuit 613

13.2.11.1 Thickeners and/or Clarifiers 514

13.2.11.2 Impoundment 518

13.2.11.3 Underground Stowage 519

13.2.11.4 Mechanical Dewatering 519

13.2.11.5 Thermal Drying or Self-Incineration 524

13.2.11.6 Chemical Additives 526

13.2.12 Preparation Plant Process Water 527

13.2.13 Coal Waste Disposal Summary 532

13.3 Air Pollution Control 532

13.3.1 Summary of Proposed Air Quality Standards 534

13.3.1.1 Selection of Pollutants for Control 535

13.3.2 Applying Dust Collection Equipment to the Coal Cleaning Process 536

13.3.2.1 Exhaust Hoods 539

13.3.2.2 Ducts 540

13.3.2.3 Mechanical Collection Equipment 541

13.3.3 Specific Applications to the Thermal Drying Process 547

13.4 Noise Pollution Control 548

13.4.1 Reduction of Preparation Plant Noises 553

13.4.2 Control of Plant Noises Intrusion Into Nearby Communities 557

14 REMOVAL OF CONTAMINANTS FROM COAL 575

14.1 Overview 575

TABLE OF CONTENTS
(Continued)

CHAPTER PAGE

REMOVAL OF CONTAMINANTS FROM COAL (Continued)

14.2 Washability Studies 580

14.2.1 Description of Testing Procedures (Float and Sink Analysis) 582

14.2.2 Description of Testing Procedures (Total Sulfur and Form of Sulfur) 586

14.3 Washability Data 592

APPENDICIES 627

Appendix I Glossary of Selected Terms 628

Appendix II Coal-Waste Disposal Inventory Questionnaire 653

Appendix III Washability Curves and the Interpretation of Float-and-Sink Data 665

Appendix IV Performance Criteria 673

Appendix V Calculation and Plotting of Distribution Curves 679

Appendix VI Predicting Cleaning Results Using Distribution Curve Data 685

Appendix VII List of Applicable ASTM Standards 691

Appendix VIII Buying Directory 693

Appendix IX English Metric Conversion Charts 725

LIST OF FIGURES

FIGURE		PAGE
1-1	U.S. Supplies and Uses of Coal (Million Tons)	2
1-2	U.S. Soft Coal Productivity by Mine Type	3
2-1	Some of the Features Affecting the Continuity of Coals	11
2-2	Faults	12
2-3	A Clay Vein Interrupting the Coal and Overlying Strata	13
2-4	Igneous Intrusion	14
2-5	The Coal Fields of the United States	29
2-6	The Coal Fields of the United States	32
3-1	By-Product Coke Oven	45
4-1	The Modern Preparation Plant	55
4-2	Preparation Plant Modules	64
5-1	Plant Feed Module Highlighted	70
5-2	Rotary Breaker	73
5-3	Bar Screens of "Grizzly"	74
5-4	Vibrating ROM Coal Screens	76
5-5	ROM "Bradford" Breaker in a Well-Controlled Environment	79
5-6	Roll Crusher in Worst Possible Environment	79
5-7	Cross-Section of Double-Roll Crusher	81
5-8	Crushing Heads	81
5-9	Open Raw and Clean Coal Storage	84
5-10	Enclosed Raw and Clean Coal Storage	84
5-11	Conical Pile and Dead Storage	87
5-12	Conical Pile With Earth Fill to Eliminate Dead Storage	87
5-13	Details of a Concrete Silo	90
6-1	Product Sizing Module Highlighted	96
6-2	Illustration of Screen Use	98

LIST OF FIGURES
(Continued)

FIGURE		PAGE
6-3	Representation of Screening Action in the Logitudinal Direction	101
6-4	Standard Type of Perforated Screen	103
6-5	Common Types of Profile Rod Screens	104
6-6	Typical Double-Deck Inclined Vibrating Screen	105
6-7	Pre-Wet Screening Operation	110
7-1	Product Separation Module Highlighted	116
7-2	Misplaced Material in the Separation Products	118
7-3	Distribution Curve of Raw Coal to Clean Coal; Coarse Versus Fine Coal Fractions	119
7-4	Examples of Coal Cleaning Equipment	122
7-5	Simplified Typical Dense-Medium Coarse Coal Washer Flowsheet	127
7-6	Dense Media Separating Vessel	128
7-7	Mechanical Coal Removing System	129
7-8	Middling Product Removal System	129
7-9	Refuse Removal System	130
7-10	Drain and Rinse Screens	130
7-11	Dense and Dilute Media Sump and Pump	131
7-12	Magnetite Recovery Unit	132
7-13	Recovery of Magnetite from Spent Media	132
7-14	Makeup Water Head Tank	133
7-15	Magnetite Feed and Density Control System	133
7-16	Magnetite Recovery Circuit	135
7-17	The Dense Media Chance "Sand Cone"	139
7-18	McNally Tromp Dense Media Vessel	143
7-19	McNally Tromp Three-Product Vessel	144
7-20	McNally Lo-Flo Vessel	146
7-21	DMS Dense Media Coal Washer	146
7-22	Link-Belt Tank-Type Heavy Media Coal Washer	148
7-23	Barvoy Heavy Media Vessel	149

LIST OF FIGURES
(Continued)

FIGURE		PAGE
7-24	DSM Shallow Bath Vessel	150
7-25	H&P Heavy Media Wash Box	151
7-26	Simulated Results of Stratification Process in a Coal Washing Jig	153
7-27	Typical Baum-Type Jig	155
7-28	Various Stages in the Stratification Process	158
7-29	McNally Norton Standard Washer	162
7-30	McNally Mogul Washer	163
7-31	McNally Mogul Washer as Observed in a Preparation Plant	164
7-32	McNally Giant Washer	165
7-33	Baum Jig Cross-Section	166
7-34	Side View Cross-section of Batac Jig	167
7-35	Batac Jig Cross-Section	169
7-36	A Dense Media Cyclone and the Idealized Flow Pattern Within	172
7-37	Typical Dense Media Cyclone Circuit	177
7-38	Hydrocyclone Cross-Section and Flow Diagram	179
7-39	Typical Deister Table Installations	184
7-40	Rubber Riffles on a Concentrating Table	185
7-41	A Fully Loaded Table in Good Adjustment	185
7-42	The Distribution of Table Products by Particle Size and Specific Gravity	187
7-43	Contributing Equipment to the Fine Coal Circuit	191
7-44	The Flotation Concept	193
7-45	Coal Laden Froth	194
7-46	Typical Multi-cell Froth Flotation Installation	194
7-47	Floatability as a Function of Particle Size	195
8-1	Product Dewatering Module Highlighted	211
8-2	Natural Drainage Via a Bucket Elevator	213
8-3	Typical Vibrating Screen Installation	213

LIST OF FIGURES
(Continued)

FIGURE		PAGE
8-4	Screens Used in a Typical Heavy Media System	219
8-5	Solid Recovery Screen Applications	224
8-6	Running the Screen Product Uphill	225
8-7	Sieve Bend	228
8-8	Schematic Diagram of a Sieve Bend	229
8-9	Vor-Siv	231
8-10	Centrifugal Force Diagram	234
8-11	Bird Solid Bowl Centrifuge	236
8-12	Perforate Basket Centrifuge	238
8-13	Horizontal Vibrating Basket Centrifuge	240
8-14	Vertical Vibrating Basket Centrifuge	241
8-15	Operational Diagram of a Coal Vacuum Filter	243
8-16	Individual Filter Compartments	244
8-17	Standard Vacuum Filter Installation	244
8-18	Rotary Drum Coal Filter	246
8-19	Filtration Rate Versus Feed Solids	247
8-20	Schematic Diagram of a Typical Fine Coal Filter Circuit	249
8-21	Typical Thermal Coal Dryer	252
8-22	The Thermal Dryer	256
8-23	Obvious Air Pollution Problems When Unchecked	256
8-24	Hydraulic Cone	256
8-25	Typical Hydraulic Cyclone Installation	262
8-26	A Working Screw Classifier	262
9-1	Storage and Shipping Module Highlighted	276
9-2	Conical Shaped Stockpile	281
9-3	Wedge Shaped Stockpile	283
9-4	Kidney Shaped Stockpile	284
9-5	Steel and Concrete Storage Silos	285
9-6	Monolithic Concrete Bin	286

LIST OF FIGURES
(Continued)

FIGURE		PAGE
9-7	Flood Loading From Steel Surge Bin	287
9-8	Two-Silo Unit Train Loading System	289
9-9	Minimal Unit Train Loading Facility	290
9-10	Maximized Unit Train Loading Facility	291
9-11	Car Haul System of Unit Train Loading	291
9-12	Unit Train Loading With Moveable Tripper	292
9-13	Unit Train Being Loaded Out in a Western Mine	294
9-14	Barge Loading with Moveable Tripper	295
9-15	Various Barge-Loading Facilities	296
10-1	Continuous Aerial Tramway	304
10-2	Three-roll Idler Conveyor Belt System	305
10-3	Combination Conveyor and Truck Refuse Handling System	307
11-1	Flowchart for a Complete Preparation Plant	315
11-2	Flowchart for Coarse Size Coal Circuit	317
11-3	Highlights of the Drain and Rinse Process in the Coarse Coal Circuit	317
11-4	Flowchart for Intermediate Size Coal Circuit	321
11-5	Flowchart for Fine Size Coal Circuit	325
11-6	Refuse Recovery Circuit	328
11-7	Product Quantities	332
11-8	Sensitivity Analysis for Metallurgical Coal	333
11-9	Sensitivity Analysis for Steam Coal	334
11-10	Typical Washability Curves	340
11-11	Determination of Economical Washing Specific Gravities	341
12-1	Typical Disposal Sites	358
12-3	Potential Fugitive Emission Sources	366
13-1	"Dump" Disposal Site	401
13-2	Planned Refuse Site	401

LIST OF FIGURES
(Continued)

FIGURE		PAGE
13-3	Refuse Disposal System Development Flow Chart	405
13-4	Refuse Disposal System Development Flow Chart	406
13-5	Coefficient of Permeability (ft/day)	407
13-6	Gradation Summary, Coarse Coal Refuse	422
13-7	Gradation Summary, Coarse Coal Refuse	424
13-8	Gradation Summary, Coarse Coal Refuse	425
13-9	Gradation Summary, Fresh Coarse Coal Refuse	426
13-10	Atterberg Limits, Coarse Coal Refuse	428
13-11	Natural Moisture Content, Coarse Coal Refuse	430
13-12	In-Place Dry Density, Coarse Coal Refuse	431
13-13	Compressibility Charts, Coarse Coal Refuse	435
13-14	Shear Strength Parameters, Coarse Coal Refuse	436
13-15	Gradation Summary, Fine Coal Refuse	439
13-16	Natural Moisture Content, Fine Coal Refuse	440
13-17	In-Place Dry Density, Fine Coal Refuse	442
13-18	Compaction Charts, Fine-Grained Coal Refuse	443
13-19	Compressibility Charts, Fine Coal Refuse	447
13-20	Shear Strength Parameters, Fine Coal Refuse	448
13-21	Simple Dump Forms	455
13-22	Simple Impoundment Forms	464
13-23	Basic Stability and Hazard Diagram	494
13-24	Thickener Tank Designs	515
13-25	Standard Tunnel Solids Withdrawal System	516
13-26	Impact of Polymer on Solids Recovery	523
13-27	Plant Refuse Removal and Some Optional Methods of Disposal	533
13-28	A Packed-Bed Scrubber	545
13-29	Typical Impingment Scrubber Design	546
13-30	Venturi Scrubber Shown as Part of a Complete Coal Dryer	549

LIST OF FIGURES
(Continued)

FIGURE		PAGE
13-31	Maximum Daily Noise Exposure Permitted By MESA	552
14-1	Estimated Costs of Sulfur Removal Potential of Different Emission Control Strategies	578
14-2	Flow Diagram Showing Preparation of Face Samples	584
14-3	Nomograph Relating Sulfur Content and Calorific Value in COals to Pounds of SO_2 Emission Per Million Btu	613
14-4	The Effect of Crushing to 1 1/2 inch, 3/8 inch and 14 Mesh Top Size on the Reduction of Ash, Pyritic Sulfur, Total Sulfur and Pounds SO_2 Emission per Million Btu at Various Specific Gravities of Separation for All U.S. Coals	614
14-5	Percent of All U.S. Coal Samples Meeting the Current EPA Standard of 1.2 Pounds SO_2/MM Btu with no Preparation, Curve a; Compared with Those Crushed to 1 1/2 inch Top Size at a Btu Recovery of 90 Percent, Curve b; and Those Crushed to 14 mesh Top Size at a Btu Recovery of 50 Percent, Curve c, and Separated Gravimetrically	615

LIST OF TABLES

TABLE		PAGE
2-1	Classification of Coals by Rauls	16
2-2	Grindability Indexes of Some American Coals	20
2-3	Minor and Trace Elements in Coal	23
4-1	Preparation Plant Capital and Operating Costs	56
4-2	Comparative Coal Costs for Utility Consumption Utilizing Cleaned Coal and Run-of-Mine Coal From The Same Mine	61-62
5-1	Sizes and Capacities of Rotary Breakers	80
5-2	Capacities and Double-Roll Crushers	82
8-1	TPH Capacity of Vibrating Screens Dewatering Presized Coal at 1/4"	217
8-2	TPH Capacity of Vibrating Screens Dewatering Coarse Presized Coal at 1/2 mm	217
8-3	TPH Capacity of Vibrating Screens Dewatering Fine Coal at 1/4 mm	217
8-4	TPH Capacity of Vibrating Screens Dewatering Fine Coal at 1/2 mm	218
8-5	TPH Capacity of Vibrating Screens Dewatering Fine Coal at 1 mm	218
8-6	TPH Capacity of Single Deck Low-Head Media Recovery Screens at 1/2 mm	221
8-7	TPH Capacity of Combination Sizing, Dewatering and Desliming Screens Handling 3/8" x 0 or 1/4" x 0 coal	222
8-8	TPH Capacity of Solids Recovery Screens Receiving Only Fine Coal Feed 1 mm or 1/2 mm x 0	226
8-9	TPH Capacity of Solid Recovery Screens Receiving 1/4" x o Coal + Thickened Fine Coal Slurry	226
8-10	36 Inch Diameter Positive Discharging Perforate Basket Centrifuging Performance	287
8-11	Typical Performance Data for Vertical Vibrating Basket Centrifuges	239
8-12	Pressure Versus Disc Filter	245
8-13	Typical Performance of a 14 Inch Diameter Hydraulic Cyclone	261

LIST OF TABLES
(Continued)

TABLE		PAGE
11-1	Percent of Coal Samples Meeting EPA Standards of 112 lbs/SO_2 Per m Btu	314
11-2	Process Quantities for a Typical 1,000 tph Coal Cleaning Plant	330
11-3	Impact of Near-Gravity Material on the Separation Process	342
12-1	Specific Gravity Results for Fine Coal Refuse	351
12-2	Distribution of Particle Sizes in Samples of Underground-Mine Refuse	354
12-3	Selected Chemical Characterists of Samples of Underground-Mine Refuse	355
12-4	Criteria for Determining Acid Mine Drainage	361
12-5	Particulate Emission Factors for Thermal Coal Dryer	368
12-6	Trace Metal Analysis of Particulate Emissions From a Coal Dryer	369
12-7	Rank Ordering of Equipment in Terms of Noise Source	372
12-8	Typical Major Equipment List in a Large Processing Plant and Associated Noise Level dB(A)	375
13-1	Specific Gravity Results for Coarse Coal Refuse	427
13-2	Compaction Characteristics--Coarse Coal Refuse	432
13-3	Specific Gravity Results for Fine Coal Refuse	441
13-4	Possible Consequences of Embankment Failure	505
13-5	Pressure Filter Use Versus Disc Filter Use	520
13-6	Combustion Product Emissions From Well-Controlled Thermal Dryers	535
13-7	Fugitive Emissions from Coal Preparation Plants	539
13-8	Permissible Noise Exposures Prescribed by the Walsh-Healy Act	
14-1	Summary of the Physical Desulfurization Potential of Coals by Region	581

LIST OF TABLES
(Continued)

TABLE		PAGE
14-2	Typical Washability Data Plus Interpolated Values Provided by U.S. Bureau of Mines	594
14-3	Screen Analyses of Upper Kittanning - Bed Coal	595
14-4	Chemical and Physical Properties of Upper Kittanning - Bed Coal	596
14-5	Detailed Washability Analysis of Upper Kittanning-Bed Coal Showing the Effecto of Crushing on the Liberation of Pyritic Sulfur (1 1/2 Inch Top Size)	597-600
14-6	Detailed Washability Anaysis of Upper Kittanning-Bed Coal Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (3/8 Inch Top Size)	601-603
14-7	Sample Washability Data From U.S. Bureau of Mines RI 8118	606-607
14-8	Detailed Washability Data Lower Kittanning-Bed Coal	608
14-9	Detailed Washability Data Lower Kittanning-Bed Coal	610
14-10	Detailed Washability Data Lower Kittanning-Bed Coal	611

I. INTRODUCTION

1.1 BACKGROUND

The oil embargo and the sudden awareness of the United States to the cost of our current dependence upon foreign energy sources has set this country forth on a project to obtain energy self-sufficiency by the early 1980's. As a direct result, the United States requirements for coal in 1985 may be as much as 1.7 billion tons per year. With the annual production of coal in the early 1970's running between 575 million to 600 million tons per year, this estimate indicates that the U. S. production of coal must triple in about 15 years. More conservative estimates, some of which were made before the energy crisis and oil embargo of 1973-74, indicated that the United States requirements would be about one billion tons per year in the early 1980's. The published goals for President Ford's Project Independence (our country's plan to achieve energy self-sufficiency by 1985) include a requirement for 1.2 billion tons of coal to be produced annually by 1985.

The mere setting of this goal to double or triple coal production over a 10 year period is not sufficient. A concerted effort by the entire country, including consumers, producers, and governmental agencies, must be made in order to obtain these goals. The projected demands which may be placed upon the coal industry come at a time when coal production, and, specifically, productivity have encountered many setbacks. Coal production in recent years has been considerably below the projected 1985 demands. In fact the total tonnage of mechanically cleaned coal in this country was actually decreasing until 1972, e.g., 335 million tons in 1969 to 271 million tons in 1971. In 1972, the total tonnage of mechanically cleaned coal increased for the first time since 1967 to a total of 289 million tons. Figure 1-1 delineates the U.S. coal production and related consumption in the period 1950-1974.

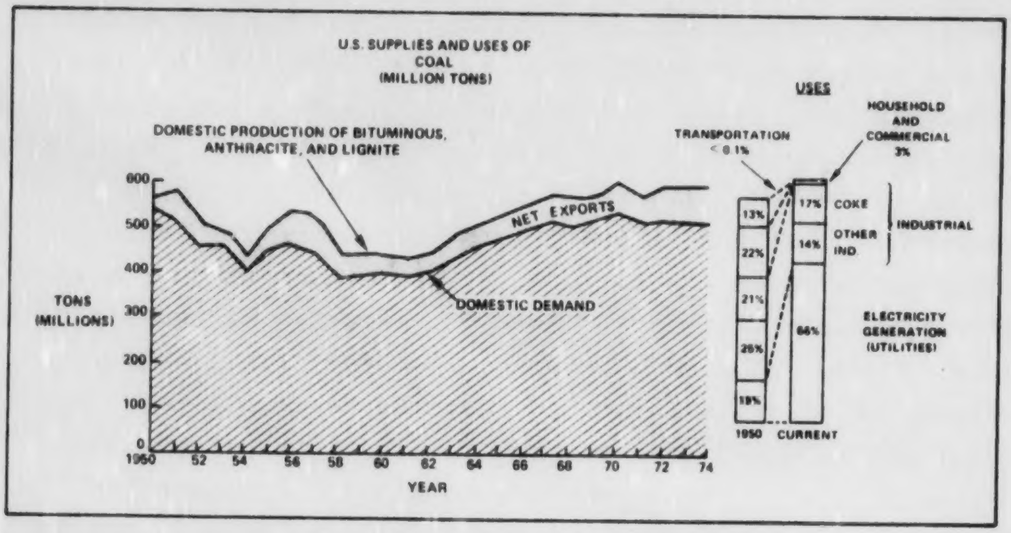

Figure 1-1
U.S. Supplies and Uses of Coal (Million Tons)

While U.S. production of coal fluctuated between 400 and 600 million tons annually since 1950, the productivity (production per man shift) enjoyed a nearly uninterrupted rate of increase. This increase in productivity in all types of mines held true until the enactment of the Coal

Mine Health and Safety Act of 1969 which appears to have reduced the productivity of underground coal mining. Strip mining has continued to enjoy increases in productivity, however. Figure 1-2 shows the productivity of U.S. coal mines from 1910 to 1974.

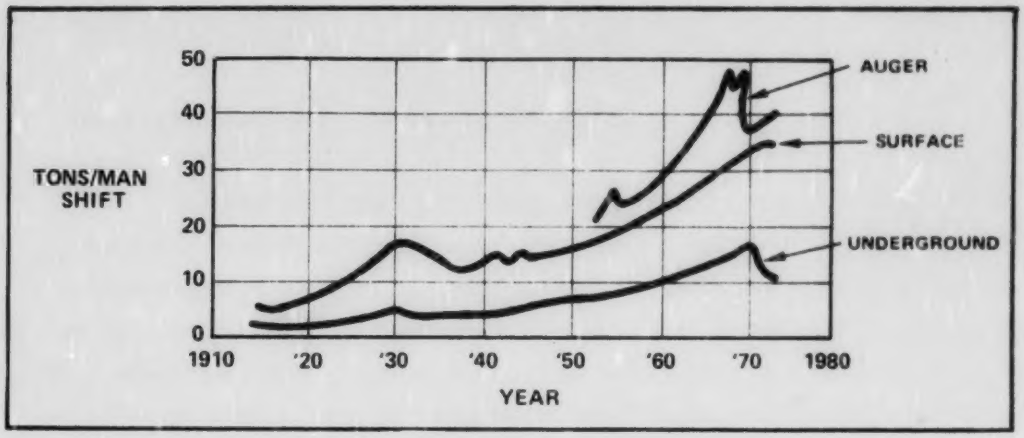

Figure 1-2
U.S. Soft Coal Productivity by Mine Type

Assuming that the industry is unable to make dramatic improvements in productivity in existing mines and that 600 million additional tons of coal annually are required by 1985, then 70% of the projected 1.2 billion annual tonnage must come from mines not now in existence. Specifically, enough new mines must be opened to produce an additional 600 million tons of coal annually over the next decade, in addition to mines needed to replace those that are being closed as they are worked out. According to Dr. John Fallon, then Director of the Federal Energy Administration, April 7, 1975, in a speech given to the Institute of Electrical and Electronics Engineers, the following action will be necessary to achieve the 1985 production levels:

- Develop 140 new 2 million ton per year Eastern underground mines,
- develop 30 new 2 million ton per year Eastern surface mines,
- develop 100 new 5 million ton per year Western surface mines,
- recruit and train 80 thousand new Eastern coal miners and
- recruit and train 45 thousand new Western coal miners.

This plan of action is ambitious to say the least. Disregarding the long-term problems confronting the coal industry, the short-run obstacles alone are considerable. To open a new coal mine takes many years lead time; normally eighteen months are required to develop a new surface mine, and five to nine years are required to develop a new underground mine. To achieve an increase in coal production of 600 million tons per year by 1985 will require that, on the average, one new underground mine (2 million tons/yr.) and one new surface mine (5 million tons/yr.) be brought into production every month for the next ten years. In contrast, only 13 mines with capacity greater than 2 million tons per year were brought into production during the decade of the 1960's.

It is certainly feasible for the industry to open the new mines and produce the extraction equipment required. Assuming it can also solve the manpower requirements, the next step toward increased coal production is coal benefaction equipment and the facilities in which the coal is cleaned. It will be necessary to design and construct as many coal preparation plants as new coal mines. The old philosophy that one need only extract the coal from the ground and allow the consumer (primarily electric utilities) to worry about the processing and consumption of the coal is being altered rapidly.

With the current emphasis on coal utilization and with the mounting concerns over the waste disposal practices of the coal mining industry, it is imperative that individuals involved with the coal production industry, and specifically those involved with the monitoring of this industry, have a basic understanding of the processes and techniques of the physical cleaning of coal, the known potential pollutants, and the current practices for control of these pollutants.

1.2 PURPOSE

The purpose of this manual is to provide an introduction to and assessment of the physical cleaning of coal together with its environmental impact. Specifically, this manual covers the general characteristics of the coals found in the United States, provides an overview of the coal preparation plant, discusses the major equipment and processes currently utilized in the physical cleaning of coal, identifies the primary wastes produced during the coal cleaning operation, and discusses the techniques of control currently applied to those wastes. The information contained will provide an overview of the state-of-the-art of the physical cleaning of coal, together with an understanding of the environmental issues and concerns which need to be addressed.

1.3 ORGANIZATION

The manual is organized in such a way that it will allow the reader to absorb the material he needs without having to read the entire work. The nature of coal, its origin, some of its basic properties and the objectives of physical coal cleaning are discussed in Chapters 2 and 3.

A generalized discussion of the coal preparation operation, the coal cleaning plant, process modules and process flow sheets are provided in Chapter 4. Chapters 5 through 10 address the major activities within the coal preparation plant as defined in Chapter 4.

Chapter 11 reviews the coal preparation plant in total, providing insight into the quantities of coal, refuse and transporting media in each of the generalized areas discussed in Chapters 5 through 10. In addition, the subject of relative cost for the cleaning of coals of different sizes at different levels is addressed to assist the reader in developing or analyzing the cost/benefit relationship of coal beneficiation.

Chapters 12 and 13 discuss the known waste streams emanating from the coal cleaning operation as they originate within the preparation plant and the current practice of minimizing and controlling those waste streams.

REFERENCES AND/OR ADDITIONAL READING

Bailey, Ralph E., "Coal Industry Overview", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania May 1975

National Coal Association, "Bituminous Coal Facts - 1970"

National Coal Association, "Coal Makes the Difference", 56th National Coal Association Convention, June 1973

Resource Planning Associates, Inc., "Energy Supply/Demand Alternatives for the Appalachian Region--Executive Summary", Council for Environmental Quality, Appalachian Regional Commission and the National Science Foundation, Report EQ-022, March 1975

U.S. Bureau of Mines, "Bituminous Coal and Lignite Shipments from Coal Producing District by Ranges of Sulfur Content (Calendar Year 1970)", Division of Fossil Fuels, 1973

W.A. Wahler & Associates, "Analysis of Coal Refuse Dam Failure--Volume I", National Technical Information Service, Springfield, Virginia, February 1973

Williams, Cyril H., Jr., "Planning, Financing and Installing a New Deep Mine in the Beckley Coal Bed", Mining Congress Journal, August 1974

Yancik, Joseph H., "Research to Improve Coal Mining Productivity", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Zitting, Richard T., "Solid Fuels: Their Contribution to Energy Independence", American Mining Congress Convention, October 1974

2. THE NATURE OF COAL

2.1 COAL AND ITS ORIGIN

Coal may be defined as a combustible material formed from accumulations of plant material: trees, (including--roots, trunks, bark, leaves), bushes, ferns, pollen and spores. During the time most coal was formed, the air was very humid. Many of the plants were huge ferns and trees which died and were replaced time after time for thousands of years. The growing accumulations of the dead and dying material in a swamp or bog gradually became rotten soggy masses commonly referred to as peat.

During the Pennsylvanian Age, 300 million years ago, the great peat swamps of North America extended over enormous areas along wide coastal plains. These swamps provided sufficiently wet conditions to permit exclusion of air from much of the vegetable materials before decay could begin and the rapid accumulation of the materials thwarted bacterial action. In addition, acidity of swamp water normally prevented bacterial action at a few inches or a few feet below the water level. As the peat accumulated, the weight of the top layers compacted the lower layers by squeezing out large amounts of water.

After a while, large areas of the earth's surface sank and streams and oceans invaded the swamps carrying salt water, clay mud and sand. The salt water killed the remaining plants and the peat accumulations were buried

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beneath tons of clay and sand. The burial of the peat by the sediment accompanied by the physical and chemical effects associated with the changed environment and by the loss of water and volatile matter resulted in a change of color and appearance of the peat; the peat became lignite, which is the lowest ranked coal.

Successive invasions of the sea and the piling of layer upon layer of sedimentary material resulted in the deep burial of the lignite deposits. Deep burial resulted in a rise in temperature, and the additional pressure squeezed out more of the retained swamp gases and moisture. These activities contributed to the process of "coalification" or the completion of the metamorphosis of the plant debris and the formation of bituminous coal.

In some geographic areas and under special circumstances, still another step occurred in the coalification process. The layers of coal, together with the underlying and overlying strata, were subjected to awesome compressive forces as the great plates of the earth's crust moved and pushed against each other forming mountainous folds. This wrinkling of the crust produced high temperatures, and the coal, thus heated and compressed, changed again; this time the resulting product is called anthracite.

Many geological factors influence thickness, continuity, quality and mining conditions of coal. Some geological features occurred during peat accumulation or shortly thereafter, others occurred millions of years later. The recognition of the nature of these features is important in the mining operation and ultimately affects the physical cleaning of the coal. Several of the more common features that affect coal cleaning are described below.

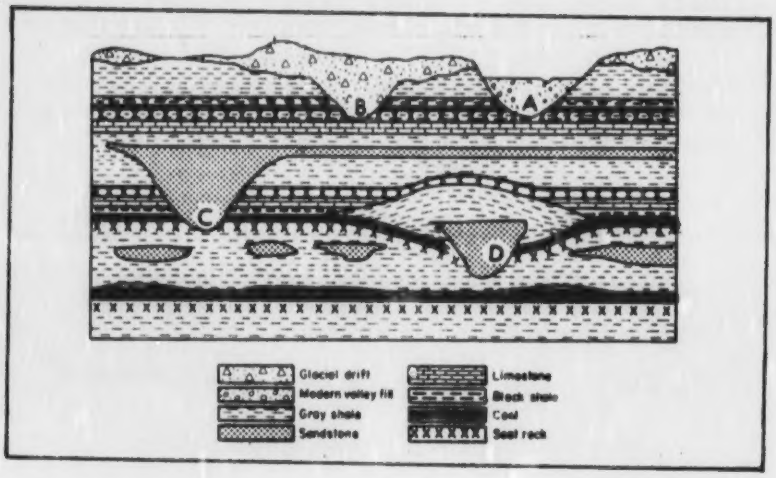

Figure 2-1

Some of the Features Affecting the Continuity of Coals

Coal removed by modern stream erosion at A; preglacial erosions at B; by a stream after coal deposition at C; and at D, the stream was present throughout the time of peat accumulation.

- Shale partings--streams periodically flood the peat swamps where the vegetable material accumulates, depositing mud and silt layers that become bands of slate and siltstone after the vegetable material is coalified. In general, the closer the peat beds were to the flooding stream, the thicker the deposits left and the more total was the disruption to the bed.

- Washouts--after the plant material has been accumulated and buried by various sediments, it may be removed by the erosive actions of streams. This activity is called a washout. Washouts may occur shortly after deposition of the peat or after coalification is complete.

- Faults--Faults are fractures in the rock sequence along which the strata on each side of the fracture appear to have moved in different directions. The movement may be measured from inches to miles and in any direction from horizontal to vertical. Two of the most common types of faults observed are illustrated below.

Where stresses are in opposite directions, rocks have been pulled apart at the fracture surface and displacement is as illustrated for a "normal fault". Where horizontal compressive forces are responsible for faulting, one block may be shoved over the other producing a "thrust" or "reverse fault".

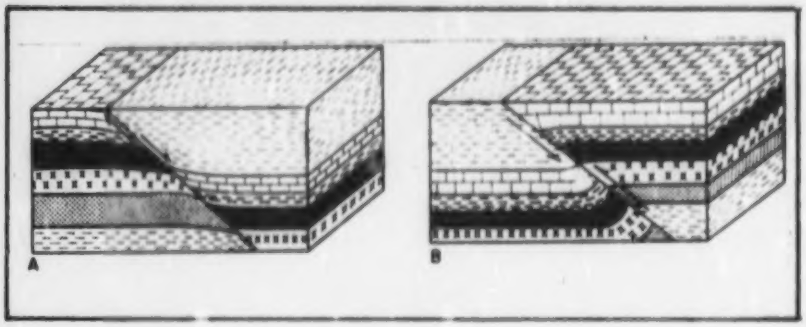

Figure 2-2
Faults

With Normal Fault (A) strata above fault have moved down to those above; with Reverse Fault (B) strata above have moved up.

- Clay veins--irregular, vertical to inclined tabular masses of clastic material (clay, sand or silt) that interrupt the coal seam are called clastic dikes or "clay veins" (see Figure 2-3). These clay veins may be from a fraction of an inch to several feet thick and may extend for some distance into the strata overlying the coal. They frequently contribute to roof instability as the coal is mined. The clay veins tend to be numerous in some areas and commonly intersect each other. They add to the waste material that must be removed from the salable coal as well as creating safety hazards and drainage problems.

- Concretions--the coal as well as the associated rocks commonly contains aggregations of minerals in spherical, disc-like or irregular forms. They may be microscopic or several feet across, although the most commonly observed size is several inches wide. Mine and roof shales commonly contain concretions made up of Calcite ($CaCo_3$), Dolomite ($CaMg(CO_3)_2$), Siderite ($FeCO_3$) and Pyrite (FeS_2). The presence of large concretions in mine roof material may have a considerable effect upon roof stability creating safety hazards and adding to the waste material. In the coal headed for a preparation plant, pyritic concretions are common, ranging from less than an inch to several feet and are usually referred to as sulfur balls.

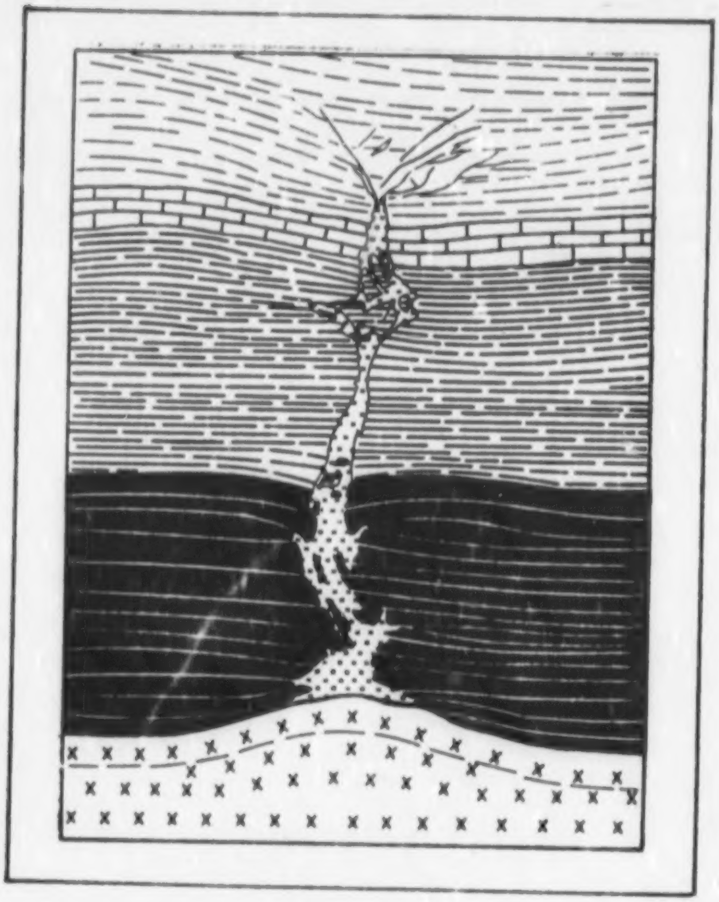

Figure 2-3
A Clay Vein Interrupting the Coal and Overlying Strata

- Igneous Intrusions--in some areas, the coal and associated strata may have been intruded by once-molten igneous rocks forcibly injected into the sedimentary sequence from below. The igneous rock is commonly seen as a dike which is a nearly vertical tabular mass cutting across the bedding of the sediments. Depending on the size of the igneous mass and its temperature, the coal is thermally affected, being either advanced in rank or coked immediately adjacent to the igneous body. The igneous rocks that occur within a coal seam are much harder than the coal which may cause mining problems and contribute to preparation problems.

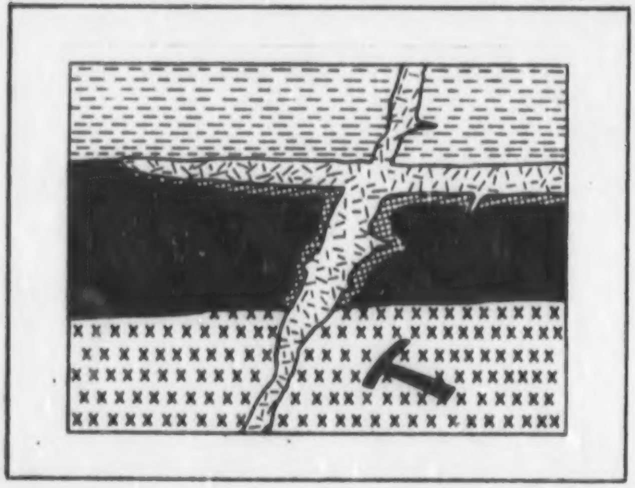

Figure 2-4
Igneous Intrusion

An igneous dike cuts through a coal bed and spreads out into a sill at the top of the bed. A thin zone adjacent to the igneous rock has been thermally altered to natural coke.

2.2 PROPERTIES OF COAL

The material we call coal is classified by a series of chemical analyses and physical tests which define the coal in its various stages of metamorphism. Coal increasingly metamorphoses (responds to pressure and heat) from lignite and subbituminous ranks through the high-volatile, medium-volatile, low-volatile bituminous coal ranks to anthracite and meta-anthracite. Coalification is a gradual process and the classification of coal by ranks is just an identification of the various stages of that process and is based upon such properties as the percentage of fixed carbon, the percentage of volatile matter, calorific value and the agglomerating character as shown in Table 2.1. However, the classification by ranks does little to describe the overall complexities of the chemical and physical composition of different coals.

Coal is a very complex material and its chemical composition varies widely. The principle differences between coals can be traced to the different plant assemblages in the original forest, and to the history of the coal bed since it was formed.

The original peat bogs and coastal swamps were occasionally subjected to flooding by streams from adjacent hills. As this happened additional clay and silt were deposited in the swamp. These additional deposits became mixed with the plant debris and are responsible for the ash content of the coal: The muddier the original bog, the greater the ash content of the coal. As the peat became buried, other changes occurred. The deeper it was buried, the greater the compression and heat experienced by the bed. The greater the compression and heat, the more the volatile constituents were removed: The more volatiles removed, the greater the carbon content of the coal.

Table 2-1

Classification of Coals by Rank

Class	Group	Fixed Carbon Limits, % (Dry Mineral-Matter-Free Basis)		Volatile Matter Limits, % (Dry, Mineral-Matter-Free Basis)		Calorific Value Limits, Btu per Lb (Moist,[b] Mineral-Matter-Free Basis)		Agglomerating Character
		Equal or Greater Than	Less Than	Greater Than	Equal or Less Than	Equal or Greater Than	Less Than	
I. Anthracitic	1. Meta-anthracite	98	..	..	2	..	..	Nonagglomerating
	2. Anthracite	92	98	2	8	..	..	
	3. Semianthracite[c]	86	92	8	14	..	..	
II. Bituminous	1. Low-volatile bituminous coal	78	86	14	22	..	..	Commonly agglomerating[e]
	2. Medium-volatile bituminous coal	69	78	22	31	..	..	
	3. High-volatile *A* bituminous coal	..	69	31	..	14,000[d]	..	
	4. High-volatile *B* bituminous coal	..	..	..	..	13,000[d]	14,000	
	5. High-volatile *C* bituminous coal	..	..	..	..	11,500	13,000	
						10,500	11,500	Agglomerating
III. Subbituminous	1. Subbituminous *A* coal	..	..	..	..	10,500	11,500	Nonagglomerating
	2. Subbituminous *B* coal	..	..	..	..	9,500	10,500	
	3. Subbituminous *C* coal	..	..	..	..	8,300	9,500	
IV. Lignitic	1. Lignite *A*	..	..	..	..	6,300	8,300	
	2. Lignite *B*	..	..	..	..	..	6,300	

---

[*] From: American Society for Testing and Materials, D 388.

[a] This classification does not include a few coals, principally nonbanded varieties, which have unusual physical and chemical properties and which come within the limits of fixed carbon or calorific value of the high-volatile bituminous and subbituminous ranks. All of these coals either contain less than 48% dry, mineral-matter-free fixed carbon or have more than 15,500 moist, mineral-matter-free Btu per lb.

[b] Moist refers to coal containing its natural inherent moisture but not including visible water on the surface of the coal.

[c] If agglomerating, classify in low-volatile group of the bituminous class.

[d] Coals having 69% or more fixed carbon on the dry, mineral-matter-free basis shall be classified according to fixed carbon, regardless of calorific value.

[e] It is recognized that there may be nonagglomerating varieties in these groups of the bituminous class, and there are notable exceptions in high-volatile *C* bituminous group.

Source: United States Bureau of Mines

In order to classify coal, we must be able to recognize the different classes. This recognition is accomplished on the basis of identification of unique characteristics. The characteristics which permit the distinction between two specimens of coal are called properties. The physical properties are concerned with the characteristics of coal in its natural state, or prior to its end use as a fuel. For example, the hardness of coal determines the maintenance cost on coal handling equipment; the specific gravity of coal determines the coal preparation techniques used in a cleaning plant as well as the capacity of coal bins, boats and size of cargo and other coal storage facilities. The physical properties are, of course, dependent upon the chemical constituents that make up coal. The chief physical properties important to coal preparation are:

- Specific Gravity
- Size Stability and Uniformity
- Friability
- Resistance to Weathering
- Grindability
- Presence of Impurities

The chemical constituents that are important to coal preparation relate primarily to the impurities in the coal, i.e., those that are not carbon such as moisture, ash, pyrite, sulfur, etc.

2.2.1 Specific Gravity

The density of coal is its weight per unit of volume. The specific gravity of coal is its density referred to the density of water at 4°C. Various values ranging from 1.23 to 1.72 are recorded in literature for the specific gravity of "pure" coal. The variations are due to differences in rank, differences in moisture and ash content and differences in methods used to determine specific gravity. The specific gravity of clean coal increases with rank and ranges from lignite to anthracite. Coal of a given rank has a higher apparent specific gravity when wet than when dry, and similarly, a change in specific gravity is exhibited with the change in ash content: Higher ash content gives higher specific gravity. The most important use of this physical characteristic is the part that it plays in the cleaning of coal by wet cleaning methods. The basic principle on which these operate is that the specific gravity of coals differs from their associated impurities and that there is a relationship between the velocity with which the particles fall in water and their relative densities.

Shale, clay and sandstone, if pure, have a specific gravity of about 2.6. Carbonaceous shale ranges in specific gravity from 2.0 to 2.6 depending upon the quantity of carbonaceous material present. Other impurities such as gypsum, kaolin and calsite have specific gravities of 2.3, 2.6 and 2.7, respectively, while the specific gravity of pyrite is about 5.0. Since the specific gravities of all these impurities are considerably greater than the specific gravity of coal, these impurities will fall to the bottom of a container filled with water more rapidly than coal. If the water is given a pulsating motion by compressed air, for example, causing the water to move up and down, the impurities will be kept at the bottom and the coal at the top where it can be recovered.

2.2.2 Size Stability and Uniformity

Size stability and uniformity of a given coal are critical to the coal cleaning operation because the cost of cleaning the coal increases dramatically as the percentage of fine size coal in the preparation plant increases. The size stability of coal may be expressed as a function of friability and/or weathering.

2.2.2.1 Friability--The strength of coal is displayed, among other ways, in its ability to withstand degradation of size upon handling. The tendency towards breakage during handling, termed "friability", depends to some extent on the toughness, elasticity and fracture characteristics as well as upon strength. The greater the friability of a given coal, the greater the chance for size degradation, e.g., very friable coal will produce a larger percentage of fines when the coal is fed to a crusher.

Friability normally increases with coal rank (with the exception of anthracites) reaching a maximum in coals of the low-volatile group. Coals of somewhat lower rank than low-volatile are usually relatively non-friable and, hence, resist degradation in size with its accompanying increase in the amount of surface exposed to oxidation. With coals of subbituminous rank, degradation by slacking or weathering supplements that due to breakage or handling. Anthracites are compared in friability to the subbituminous coals; both are harder than bituminous coals and decidedly more resistant to breakage than the very friable low-volatile coals. Lignites were found to be the least friable of all coals.

2.2.2.2 Weathering--Weathering is the tendency of coals to disintegrate or slack on exposure to weather, particularly when alternately wetted and dried or subjected to hot sunshine. Lower ranked coals like lignite slack very readily; subbituminous coals slack to some extent but less readily than lignite; and bituminous coals are affected only slightly by weathering. The size degradation caused by slacking is expressed as a precentage and termed slack index. Slack indexes of five percent or less characterize bituminous coals where as the slack indexes for lignite approach 100 percent.

2.2.3 Grindability

Grindability of coal, or the ease with which it may be pulverized, is a composite physical property embracing other specific properties such as hardness, strength, tenacity and fracture. A general relationship exists between the grindability of a specific coal and its rank. Coals that are the easiest to grind are found in the medium-volatile and low-volatile groups. These coals are decidedly easier to grind than coal of the high-volatile bituminous, subbituminous and anthracite ranks. The most common index of grindability is the Hardgrove grindability index. Table 2-2 shows the varying grindability of some

Table 2-2
Grindability Indexes of Some American Coals

State	*County*	*Bed*	*Hardgrove Grindability Index*
Pennsylvania	Cambria	Lower Kittanning	109
Pennsylvania	Indiana	Lower Freeport	92
Pennsylvania	Washington	Pittsburgh	55
Pennsylvania	Westmoreland	Upper Freeport	65
West Virginia	Fayette	Sewell	86
West Virginia	McDowell	Pocahontas No. 3	96
West Virginia	Wyoming	Powellton	58
West Virginia	Wyoming	No. 2 Gas	70
Virginia	Wise	Morris	43
Virginia	Wise	Taggart	62
Virginia	Dickenson	Upper Banner	84
Virginia	Buchanan	Raven	98
Illinois	Sangamon	No. 6	55
Illinois	Williamson	No. 6	57
Illinois	Fulton	No. 5	63
Illinois	Vermillion	No. 7	56
Kentucky	Pike	Elkhorn Nos. 1 & 2	42
Kentucky	Bell	Hight Splint	40
Kentucky	Muhlenburg	No. 12	55
Ohio	Harrison	No. 8	51
Ohio	Belmont	No. 9	50
Indiana	Sullivan	No. V	55
Alabama	Walker	Black Creek	44
Utah	Carbon	Castle Gate	47
Pennsylvania	Schuylkill	Various	38

United States coals. The capacity, power input for pulverizing and repair costs of pulverizers vary with the grindability index. The higher the index the easier the coal is to grind.

2.2.4 Impurities in Coal

Coal is not a uniform substance, but rather a mixture of combustible metamorphosed plant remains that vary in both physical and chemical composition. The diversity of the original plant materials and the degree of metamorphism or coalification that have affected these materials are the two major reasons for the variety of physical components in coal. This widely varying composition greatly affects the preparation characteristics of the coal.

2.2.4.1 Moisture--The percentage of moisture present in a given coal bed commonly called "bed moisture", is more or less constant throughout a given mine and is a general characteristic of the rank of the coal. Bed moisture may range from a low of 1, 2 or 3 percent in bituminous coal to a high of 45 percent in lignite. The actual moisture content of a given coal as it enters a preparation plant or a steam generator is dependent upon a number of factors in addition to its bed moisture. The mining methods used to extract the coal, the storage techniques of both the raw and the clean coal products, the method of cleaning and drying of the coal and the method of transporting the coal to user may all affect the moisture content of a coal.

The moisture in the coal, whether inherent or surface, can be considered as an impurity from the viewpoint of utilization. It is, of course, a dilutant in that it reduces available energy yield of the coal in proportion to the amount of moisture present and even in excess of this amount for some uses, especially for coal's largest single customer-- electric power generation. Not only does moisture replace potential energy in proportion to the amount present, but it further robs Btu output because the moisture must be heated to stack temperatures in the boiler furnace before it is expelled.

2.2.4.2 Minerals--The mineral impurities occurring in coal may be classified broadly into those that form ash and those that contribute sulfur. From the standpoint of coal cleaning, both the ash-forming and the sulfur-containing impurities may be subdivided into two classes--impurities that are structurally a part of the coal and hence not separable by physical means, and inorganic impurities that can be eliminated to a greater or lesser extent by crushing and ordinary cleaning methods. The relative rate at which the mineral and the organic materials accumulated in the swamp determines the physical character and ash content of the product that resulted. If organic matter predominated, the product formed was coal containing some inherited impurities. If silt predominated, a carbonaceous shale was formed. Products intermittent between these two are classified as bone or boney coal depending upon the amount of silt incorporated in their structure.

Coal ash varies greatly in its chemical composition. It is a mixture of silica (SiO_2) and alumina (Al_2O_3) which came from sand, clay, slate and shale; iron oxide (Fe_2O_3) from pyrite and marcasite; magnesia (MgO) and lime (CaO) from limestone and gypsum; the alkalis, sodium oxide and potassium oxide (Na_2O and K_2O); phosphorus pentoxide (P_2O_5); and miscellaneous amounts of trace elements. Table 2-3 shows the important minor and trace elements found in most coals. Much more detailed listings may be found in the referenced literature. The residue from these minerals after the coal has been burned is called ash. The average

Table 2-3

Minor and Trace Elements in Coal

Minor Elements (about 1% or more, on ash)	Trace Elements (about 0.1% or less, on ash)	
Pollutant:	**Named as Hazardous:**	
Sulfur	Beryllium	Cadmium
Nitrogen	Fluorine	Mercury
	Arsenic	Lead
Ash-Forming:	Selenium	
Sodium		
Potassium	**Others Analyzed:**	
Iron	**Coal Basis**	**Ash Basis**
Calcium		
Magnesium	Boron	Lithium
Silica	Vanadium	Scandium
Alumina	Chromium	Manganese
Titanium	Cobalt	Strontium
	Nickel	Zirconium
	Copper	Barium
	Zinc	Ytterbium
	Gallium	Bismuth
	Germanium	
	Tin	
	Yttrium	
	Lanthanum	
	Uranium	

ash content of the entire thickness of a coal bed is at least 2 or 3% even for very pure coals, and 10% and more for coals found in most commercial mines. Coal material that is too high in ash for ordinary use may be called bone coal, bituminous shale or black slate.

Some ash-forming impurities are so finely divided and so intimately mixed with pure coal substances that they may be considered a structural part of the coal. Impurities of this type cannot be separated from the coal by physical preparation. The chief value of determining them quantitatively is that they fix a minimum ash content of the cleanest portion of the raw coal--the so-called true, fixed, normal or inherent ash content. In the washing processes for eliminating impurities, the value of inherent ash may be approached as a limiting minimum to designate the portion of the ash content of coal that is structurally part of the coal itself and, therefore, cannot be separated by mechanical means. Other impurities are interbedded with coal and may be in thin layers or in thick rock-like deposits. Clay is the most common substance in banded impurities consisting mainly of one or more of the three common clay minerals--kaolinite, illite and montmorillinite.

2.2.4.2.1 Clay and Shale One of the principal contaminants of raw coal is clay or shale from the roof and floor or from interbedded partings. Clay presents major problems to the coal preparation plant. Approximately 95% of the coal cleaned in this country is cleaned using some type of wet processing. The majority of these wet process techniques use the difference in density between coal and its associated impurities as the basis for separating the coal from the impurities.

The pronounced tendency of clays to disintegrate in water and to form plastic masses have definite implications in terms of the design and operation of preparation plants, i.e., they show up as an additional capital cost in plant design and as an operational cost on a daily basis. The direct operational difficulties (cost) associated with the particle disintegration and the resulting dispersion of colloidal matter appear in the form:

- of contamination to and increased viscosity of dense-medium suspensions,
- difficulties in dewatering and drying of the fine coal sizes,
- difficulties in the filtration of froth-flotation products and
- handling difficulties in the disposal of fine refuse.

In addition to the items listed above and with specific reference to the low-ranked lignite and subbituminous coals, other operational difficulties arise when the lattice structure of the particular clays associated with these coals render them susceptible to swelling. These clays may swell to such a degree that their apparent specific gravity is altered significantly. This alteration brings the specific gravity of the clay down to 1.60, very close to that of the coal itself. As the specific gravity of the clays approaches that of the coal being washed, several things may happen. First, the clay becomes extremely difficult to separate from the coal. Secondly, the apparent density of the wash-bath is altered significantly allowing slate to be discharged with the coal at the top of the washer. (Specifics of the washing operation are addressed in Chapter 7.)

The problems generated by clay and shales in a washing plant appear to be related to the rank of the coal. In anthracite coal, the shale is so well indurated and compacted that it is called slate and it shows very little tendency toward particle disintegration. On the other hand, clay and shale in low-rank coals, such as subbituminous, exhibit a maximum amount of particle disintegration and an amplification of the difficulties discussed.

2.2.4.2.2 Sulfur--Of the minerals found in coal, sulfur is the most important single element impeding the utilization of coal as a clean fuel. Many U.S. steam coals contain high percentages of sulfur which must be reduced as air pollution regulations become increasingly more stringent. The reduction of sulfur in coal is a difficult problem which has long been under study.

Sulfur in coal is reported in detailed chemical analysis as sulfate sulfur, pyritic sulfur and organic sulfur. The sulfur content of coals varies from 0.1 to 10.0% by weight.

Sulfate sulfur, or that part of the total sulfur that can be extracted by treatment with hydrochloric acid, is usually of only minor importance (less than 0.1 weight percent). The sulfate sulfur occurs in combination with either calcium or iron and is usually water-soluble, originating from *in situ* pyrite oxidation. The amount of sulfate sulfur in a coal increases rapidly with weathering as the oxidation of iron sulfides gives rise to ferrous and ferric sulfates.

The term pyritic (sulfide) sulfur is used to refer to either of the two dimorphous forms of ferrous disulfide (FeS_2)--pyrite or marcasite. The two minerals have the same chemical composition, but have different crystalline forms. Pyrite is isometric (cubic) and marcasite is orthorhombic. The victorian brown coals of Australia are an exception in that marcasite is virtually the only sulfide material reported.

Microscopic pyrites occur predominantly in coal in four forms:

1. Veins--generally thin and film-like along the vertical joints (cleat), but may be up to several inches wide and contain large pyrite crystals with well developed crystal faces.
2. Lenses--extremely variable in shape and size but generally flattened and elongated in cross sections, ranging in size from a fraction of an inch thick to several inches in diameter.
3. Nodules or balls--roughly spherical in shape and from inches to several feet in diameter. These sulfur balls are usually not pure pyrite but include one or more of the following--calcite, siderite, clay minerals and organic matter.
4. Pyritized plant tissue--often included with the carbonate minerals in a "coal ball", which is a portion of coal in which the plant material has undergone replacement by inorganic material rather than coalification.

Sulfide sulfur occurs as individual particles (0.1 micron to 25 cm. in diameter) disseminated throughout all coal deposits. Pyrite is a dense mineral (4.5 gm/cc) compared with bituminous coal (1.30 gm/cc), but like coal is quite water-insoluble unless oxidized.

The organic sulfur is a part of, and chemically bonded to, the coal; it cannot be removed unless the chemical bonds holding it are broken. The amount of organic sulfur present, therefore, defines the theoretical lowest limit at which a coal can be cleaned by physical methods. Where organic sulfur is associated with certain constituents of coal, gravimetric reductions may be possible; however, organic sulfur is generally considered to be uniformly distributed throughout the coal and not amenable to reductions by conventional mechanical cleaning.

Only the sulfide and sulfate sulfur forms in coal may be removed by mechanical cleaning. The extent of that removal, which is possible (10% to 90%), is primarily a function of particle size of the pyrite and the nature of its dissemination. Very small and highly disseminated pyrite particles are nearly impossible to separate from coal. The pyrite may be of microscopic size and so intimately mixed with the coal that it cannot be liberated, or it may be predominantly coarse and readily released from the coal when crushed. For a given situation, the removable sulfur is the total sulfur less the sum of the organic sulfur and that portion of the finely disseminated pyrite which cannot be removed.

2.3 COAL RESERVES

Coal is found on every continent of the world, including Antarctica, although most of the coal deposits are found in the Northern hemisphere. According to the "Survey of Energy Resources", World Energy Conferences, coal has been mined in 70 countries of the world, however, 80% or more of all identified coal reserves occur in the United States, the Soviet Union and China.

Due to the many different methods used to estimate coal reserves, and because available information on coal varies widely, comparisons of the reserves between or among countries is very difficult. The United States Bureau of Mines and the United States Geological Survey data indicates that the United States has at least one-fifth to one-sixth of all the coal in the world. Approximately one-eighth of the land area of the United States is underlain by coal-bearing strata. These strata occur in at least 37 states. Figure 2-5 depicts the coal fields of the United States.

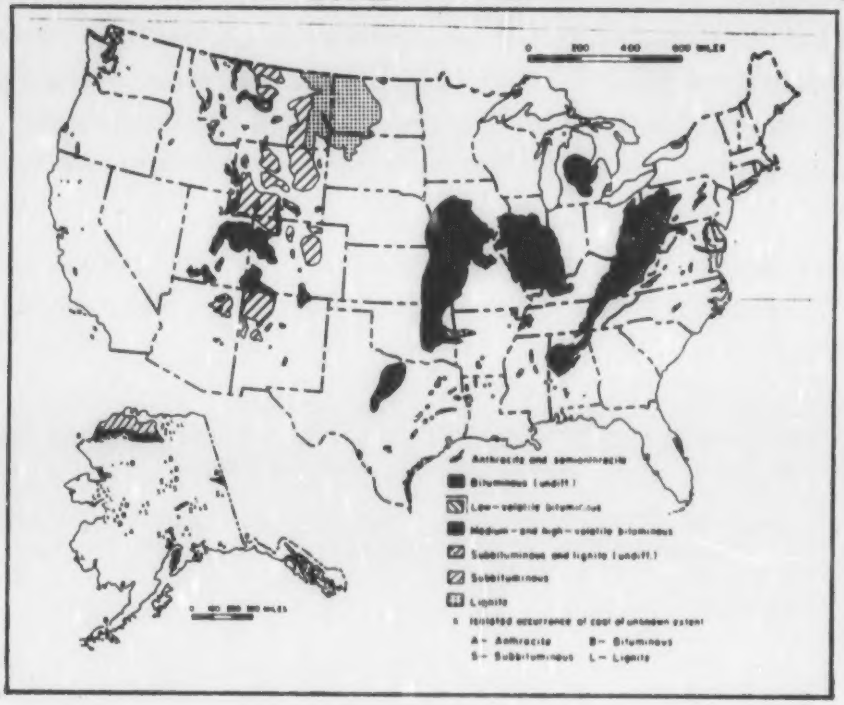
0 200 400 600 MILES
Anthracite and semianthracite
Bituminous (undiff.)
Low-volatile bituminous
Medium- and high-volatile bituminous
Subbituminous and lignite (undiff.)
Subbituminous
Lignite
Isolated occurrence of coal of unknown extent
A – Anthracite
B – Bituminous
S – Subbituminous
L – Lignite

Figure 2-5
The Coal Fields of the United States
(Source: U.S. Geological Survey)

In addition to indicating the geographic distribution of coal, Figure 2-5 shows the range of coal ranks within the United States. Nearly all the bituminous and anthracite coal is found in the Eastern half of the country. Although the full range of coal ranks is found in the Western half of the United States, most Western coal reserves are sub-bituminous coal or lignite. In most of the coal-bearing areas shown in Figure 2-5, more than one coal seam is present (from a few seams to 117 that have been identified in West Virginia). The individual seams range in thickness from a fraction of an inch to more than 100 feet. Most of the bituminous coal seams are 20 feet thick thick or less and most mining has been in seams from 3 to 10 feet thick.

According to the 1974 Keystone Coal Industrial Manual, "The identified and hypothetical reserves of coal in the United States amounts to some 3,224 billion tons. However, based on current technology, economics and environmental regulations, only some 150 billion tons could reasonably be extracted".

There are three main classes of reserves. They are: measured, indicated and inferred. They may be described as follows:

1. Measured (proven) reserves lie within 1/2 mile of a point of observation and are considered to be within 20 percent of true tonnage.

2. Indicated (probable) reserves are based on points of observation approximately 1 mile apart, but not more than 1 1/2 miles, covering a band 1 1/2 miles wide surrounding the area of proven reserves.

3. Inferred reserves, in general, lie more than 2 miles from points of observation. Sometimes this category is broken into strongly inferred reserves, which are estimated by projections beyond the 4 mile limit. The Bureau of Mines frequently reports known reserves that represent the sum of measured and indicated reserves.

In computing the volume of reserves in each of the thickness categories for each bed, the total thickness of coal is used, exclusive of partings greater than 3/8 of an inch thick. Beds or parts of beds made up of alternating layers of thin coal and partings are omitted if the total partings exceed one half the total thickness or if the ash content exceeds 33 percent. Frequently, the distribution of reserves is also categorized according to thickness of overburden: 0 to 1,000 feet, 1,000 to 3,000 feet and 3,000 feet to 6,000 feet.

The breakdown of total U.S. coal resources according to Keystone is as follows:

	Billion Tons
Mapped and explored (identified) 0-3,000 ft. overburden	1,581
Unmapped and unexplored (indicated and probable)	
0-3,000 ft. overburden	1,306
3,000-6,000 ft. overburden	337
Total	3,224

However, the economically exploitable coal, which is defined as "material having a thickness of more than 28 inches and less than 1,000 ft. overburden..." and from identified reserves, is stated to be less than 260 billion tons. Of this figure, the United States Bureau of Mines says we will recover 50% of the underground reserves (105 billion tons) and 90%+ (45 billion tons) of the surface reserves for a total of 150 billion tons.

The coal fields of the United States, identified by regions and type of mining, are shown in Figure 2.6. The Appalachian Region, which stretches northeastward from Alabama through Tennessee, Virginia, West Virginia, Ohio and Pennsylvania, is the largest deposit of high-rank bituminous coal in the world, and contains most of the anthracite coal in the United States.

One of the characteristics of the Appalachian Region coals which enhances their value is their ability to form coke or agglomerate when heated in the absence of, or with a limited supply of air. All of the coals are not used for coke-making, however, because some contain more sulfur than is desirable for metallurgical-grade coke. We have more information on the quality of these coals than for those found in any other region in the country. This is due to the many analyses of the coals made by Federal and State agencies in connection with the use of these coals, not

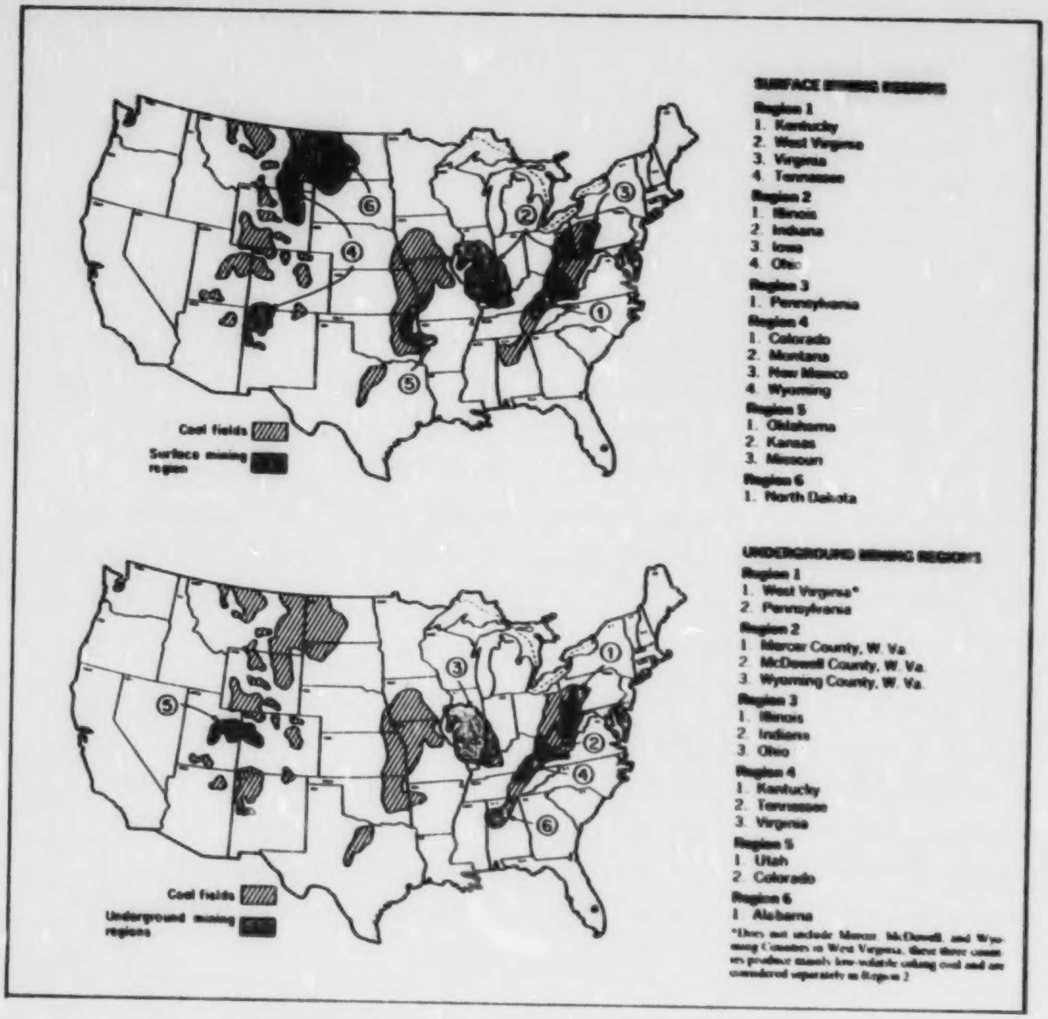

Figure 2-6
The Coal Fields of the United States
(Source: 1974 Keystone Industry Manual)

only for coke-making, but for light, power and heat in the industrial, commercial and residential sectors of the economy.

West Virginia ranks second to Illinois in total bituminous coal reserves, but first in reserves of bituminous coal among the states in the Appalachian Region. Approximately 46 percent of West Virginia's reserves are low-sulfur coals (here defined as 1.6 percent sulfur or less) and 45 percent are medium-sulfur coals (3 percent or less), making a total of 91 percent of the reserve having relatively little sulfur.

West Virginia coals vary so greatly that it is convenient to separate them as northern and southern coals. In the North, the Pittsburgh bed produces medium-sulfur coals, and the upper Freeport and Sewell beds produce low-sulfur coals that are excellent for steam generation. In the South, the Lower Kittanning, No. 2 Gas, Peerless, Cedar Grove and Sewell beds produce some of the finest steam quality coal mined in the United States. As the sulfur content of these coals is generally low, only the ash content needs to be reduced.

In Pennsylvania, large quantities of bituminous coal are produced for electric utilities. Most of this coal comes from the Upper and Lower Freeport, Upper and Lower Kittanning and Pittsburgh coal beds. These are generally medium-sulfur coals (85 percent of the reserve contains 3 percent or less sulfur and 35 percent has a sulfur content of no more than 2 percent). The Central Pennsylvania beds, including both medium and low-volatile coals, generally contain less sulfur than those in the western part of the state and are upgraded primarily to reduce the ash content before they are used for steam generation.

In Ohio the principal coal beds mined are extensions of Pennsylvania's Pittsburgh, Middle and Lower Kittanning, Upper and Lower Freeport and Sewickley (Meigs Creek) bed; these coal beds usually contain medium-ash and high-sulfur. They are used primarily for steam generation.

Maryland's coals are similar to those of the eastern portion of the bituminous fields of Pennsylvania, but these usually have low-sulfur content. In eastern Kentucky and Virginia, the coals are of low-sulfur content. In Tennessee and Alabama, the sulfur content of the coal ranges from low to high.

Of the bituminous deposits, about two-thirds are located in the states east of the Mississippi River. The coal fields or deposits in Illinois, Indiana and western Kentucky contain 29 percent of the estimated remaining bituminous coal reserve, but Illinois alone has the largest bituminous reserve of all states. Coals in these states are generally higher in sulfur, especially organic sulfur, with almost 80 percent of the reserved containing more than 3 percent sulfur. There are, however, several small deposits of low-sulfur coals in southern Illinois and Indiana where sulfur content averages 1.5 percent or less.

The Interior Western region contains large deposits of medium to high-volatile bituminous, which have not been extensively mined because they are too far from the eastern centers of population and industry. These deposits extend across Iowa, Missouri, eastern Nebraska, Kansas and into Oklahoma, with a related bed in Texas. A smaller area of low-volatile bituminous and anthracite extends over into Arkansas.

The small lignite beds in Texas and Arkansas extend over into Alabama and are properly in the Gulf Province.

They are of only fair quality and few analyses for them are available. They have been included with the interior western region in the USBM studies for convenience.

Coals in the Northern Great Plains province comprise enormous deposits of lignite and subbituminous, which have scarcely been touched. Lignite is characterized by a high content of water and ash, and an ash content of alkaline earths which is significantly higher than other coals.

The western region is defined here, as in the USBM studies of coals by regions, to include the deposits in the Rocky Mountain states and a few isolated deposits in the Pacific Northwest. A southwest sub-region at the Four-Corners area of Arizona, New Mexico, Utah and Colorado has been established for washability data collection. The coals of the western United States are geologically younger than the eastern coals, and 70% are subbituminous or lignitic in rank. Although the lower rank western coals are generally of low-sulfur content and often contain only medium amounts of ash, they also are of lower calorific value and are mostly used for steam generation where they can be mined easily and utilized close to their source. However, in some recent applications, these coals are being shipped to eastern steam generators.

On a broad regional level, only the bituminous coals of South Appalachia and some of the lignites of the West will directly, or with the best coal cleaning technology, meet the most strict sulfur emission levels, although there are other seams with substantial reserves which can comply. The coals of North Appalachia, as a group, can be prepared to meet some regional state implementation plans. Overall, the cleaning of northeastern coals combusted for power generation would result in 34% sulfur reduction (nearly 3 million tons of sulfur annually) utilizing current cleaning practice; this level would be increased to 46% (over 4 million tons annually) by the application of the best known preparation technology.

REFERENCES AND/OR ADDITIONAL READING

Allison, Ira S.; Black, R.F.; Dennison, J.M.; Fahnestock, R.K.; & White, S.M., "Geology: The Science of a Changing Earth" (6th Ed.), McGraw-Hill Book Company, New York, 1974

Baily, Ralph E., "Coal Industry Overview", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania May 1975

Barlow, James A., "Coal & Coal Mining in West Virginia", Coal Geology Bulletin No. 2, February 1974

Brobst, Donald A. & Pratt, Walden P. (Editors), "United States Mineral Resources", Geological Survey Professional Paper 820, U.S. Government Printing Office, 1973

Clenderring, John A., "Palynological Evidence for a Pennsylvanian Age Assignment of the Dunkard Group in the Appalachian Basin: Part II", Coal-Geology Bulletin No. 3, West Virginia Geological & Economic Survey, December 1974

Corp, Ernest L.,; Schuster, Robert L.; McDonald, Michael W., "Elastic-Plastic Stability Analysis of Mine-Waste Embankments", U.S. Bureau of Mines RI 8069

Dopples, Edward C.; Hopkins, M.E. (Editors), "Environments of Coal Deposition (Special Paper #114)", Geological Society of American Symposium, Miami Beach, Florida, 1964 (edited in Bouton, Colorado, 1969)

Goodrich, John C., "Computer Mapping of Coal Reserves by Sulfur Level", Harvard University, Cambridge, Massachusetts, April 1971

Helfinstine, R.J., et al., "Sulfur Reduction of Illinois Coals--Washability Studies, Phase II", Illinois State Geological Survey, July 1971

Henderson, G.S.; Andren, A.W.; Harris, W.F.; Reichle, D.E.; Shugart, H.H.; Van Hook, R.I., "Environmental Assessment of SO_2 and Trace Element Emissions from Coal Utilization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Hill, George R., "Clean Fuels from Coal--The OCR Challenge", Mining Congress Journal, February 1973

Hoffman, L; Truett, J.B.; Aresco, S.J., "An Interpretative Compilation of EPA Studies Related to Coal Quality and Cleanability", Mitre Corporation, May 1974 EPA 650/2-74-030

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Hoffman, L. et al., "Survey of Coal Availability by Sulfur Content:, Mitre Corporation, May 1972

Hulett, L.D.; Carter, J.A.; Cook, K.D.; Emery, J.F.; Klein, D.H.; Lyon, W.S.; Nyssen, G.A.; Fulkerson, W.; Bolton, N.E., "Trace Element Measurements at the Coal-Fired Allen Steam Plant--Particle Characterization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky 1974

Janssen, Raymond E., "Earth Science: A Handbook on the Geology of West Virginia", Educational Marketers, Inc., Clarksburgh, West Virginia, 1973

Jimeson, R.M.; Spindt, R.S., "Pollution Control and Energy Needs", Advances in Chemistry Series, American Chemical Society, Washington, D.C., 1973

Kennecott Copper Corporation, "Chemical Desulfurization of Coal", American Mining Congress Coal Convention, May 5-8, 1974

Lawrence, William F.; Cockrell, Charles F.; Muter, Richard, "Power Plant Emissions Control", Mining Congress Journal, April 1972

Leavitt, Jack M.; Leckenby, Henry F.; Blackwell, John P.; Montgomery, Thomas L., "Cost Analysis for Development and Implementation of a Meteorologically Scheduled SO_2 Emission Limitation Program for Use by Power Plants in Meeting Ambient Air Quality SO_2 Standards", TVA Air Quality Branch, Marcel Dekker, Inc., 1974

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Lowry, H.H. (Editor), "Chemistry of Coal Utilization", John Wiley & Sons, Inc., New York, New York, 1963

Magee; Hall; Varga, "Potential Pollutants in Fossil Fuels", Environmental Protection Technology Series, ESSO Research & Engineering Company, June 1973

Massey, Lester G., "Coal Gassification", Advances in Chemistry Series, American Chemical Society, Washington, D.C., 1974

Miller, R.E.; Agarwal, J.G.; Petrovic, L.J., "Economic & Technical Considerations in the Use of Coal as Clean Fuel", American Mining Congress Convention, May 6-9, 1973

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Nandi, S.P.; Walker, P.L., Jr., "Absorption Characteristics of Coals and Chars", National Technical Information Service, Springfield, Virginia, April 1972

National Coal Association, "Bituminous Coal Facts - 1970"

National Coal Association, "Coal Makes the Difference", 56th National Coal Association Convention, June 1973

National Coal Associaiton, "Second Symposium on Coal Utilization", NCA/BCR Coal Conference and Expo II, October 1975

Nelson, J.B., "The Assessment of the Mineral Species Associated with Coal", British Coal Utilization Research Association Bulletin 7, 2 1953

Phelps, E.R., "Federal Coal Leasing Policy", American Mining Congress Convention, October 1974

Resource Planning Associates, Inc., "Energy Supply/Demand Alternatives for the Appalachian Region--Executive Summary", Council for Environmental Quality, Appalachian Regional Commission and the National Science Foundation, Report EQ-022, March 1975

Sage, W.L., "Combustion Tests on a Specially Processed Low-Ash, Low-Sulfur Coal", National Technical Information Service, Springfield, Virginia, 1964

Schaeffer, Stratton C.; Jones, John W., "Coal Preparation vs. Stack Gas Scrubbing to Meet SO_2 Emission Regulations", NCA/BCR Coal Conference and Expo II, October 1975

Soderberg, H.E., "Environmental Energy & Economic Considerations in Particulate Control", American Mining Congress Coal Convention, May 5-8, 1974

Stacy, W.O.; Walker, P.L., Jr., "Structure and Properties of Various Coal Chars", Pennsylvania State University, National Technical Information Service, Springfield, Virginia, September 1972

Tieman, John W., "Chemistry of Coal", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York 1968

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Tieman, John W., "Geology of Coal", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York, 1968

Tompos, E., "Detailed Investigation of Pyrites Distribution, Taking Account of the Petrographic Components of Coal, with a View to Reducing the Pyrites Content in Coking Coal", Hungary, Australian Coal Conference

U.S. Bureau of Mines, "Bituminous Coal and Lignite Shipments from Coal Producing District by Ranges of Sulfur Content (Calendar Year 1970)", Division of Fossil Fuels, 1973

U.S. Bureau of Mines, "Clean Energy from Coal Technology", Overview of Coal/Energy Usage, U.S. Government Printing Office, 1974

U.S. Bureau of Mines, "Coal--Bituminous and Lignite in 1973", Division of Fossil Fuels, U.S. Department of Interior Mineral Industry Surveys, January 1975

U.S. Bureau of Mines, "Commodity Data Summaries - 1976"

Volsicky, Z.; Puncmanova, J.; Hosek, V.; Spacek, F., "Bacteriological Leaching-Out of Finely Intergrown Sulfur in Coal: Method and Features", Czechoslovakia, Australian Coal Conference

West Virginia Geological & Economic Survey, "Suitability of West Virginia Coals to Coal Conversion Processes", Coal-Geology Bulletin No. 1, December 1973

Williams, Cyril H., Jr., "Planning, Financing and Installing a New Deep Mine in the Beckley Coal Bed", Mining Congress Journal, August 1974

Yancey, J.F.; Geer, M.R., "Behavior of Clays Associated with Low-Rank Coals in Coal-Cleaning Processes", U.S. Bureau of Mines Report of Investigations #5961

Yancey, H.F., "Determination of Shapes of Particles in Coal and Their Influence on Treatment of Coal by Tables", AIME Translation, 94

Zitting, Richard T., "Solid Fuels: Their Contribution to Energy Independence", American Mining Congress Convention, October 1974

3. OBJECTIVES OF COAL PREPARATION

3.1 BACKGROUND

Coal often exists in its natural state with many impurities, i.e., sulfur, clay, rock, shale and other inorganic materials generally called ash. During the past decade increasing emphasis has been placed on removing the impurities, especially those which result in sulfur oxide emissions upon combustion of the coal.

Historically, in the United States coal preparation has been utilized only for specific coals destined for carbonization. The reasons are varied; primarily to reduce their sulfur content, to provide a specific uniform product, to enhance salability, and to improve the economic advantages for coal marketing by developing a superior product. The technological and economic growth of the last 25 years, the resulting degradation of our Nation's environment and the introduction of emission standards for air pollution control (sulfur oxides) have changed this picture considerably in recent years.

Years ago, in the hand-loading days of our coal industry, the quality of coal produced was generally satisfactory (regardless of use) because only the cleanest seams were mined and the majority of impurities inherent in mining operations were not loaded out with the coal. However, productivity per man was very low. Mechanization improved productivity, but impurities increased to the extent that some form of cleaning became necessary at many mines, even those in the cleanest seams. The transformation from hand-loading to mechanical mining was quite rapid during the mid 1930's. Tipples and earlier type cleaning devices became inadequate almost overnight. The quality of coal was jeopardized again with the adoption of full-seam mining throughout the industry. Cleaning units were installed on coarse coal sizes to eliminate the manpower required for hand picking the coal as it came from the mine. In addition, due to the marked increase in finer sizes in the run-of-the-mine coal called "ROM", cleaning units were installed to pick up the slack in the coal output.

Today with the thinner dirtier seams being mined, the impurities in the raw coal may be not only from the seam itself, but also in extraneous material taken in mining of the roof or floor. With increased mechanization, a higher proportion of top and bottom material is taken in mining, which increases the tonnage of reject to be handled. Also, the effects on mining practice of the coal mine Health and Safety Act of 1969 have contributed significantly to the increase in impurities in the ROM coal. For example, the water sprays on continuous miners used to ally the dust at the face seem to add significantly to the moisture content of the raw coal while excessive rock dusting adds other incombustibles to the ROM coal.

3.2 CURRENT PRACTICE

Coal is providing an increasing share of energy consumed by stationary sources (utility, industrial, commercial and residential). Demand for electrical energy, the shortage of available oil and gas and stagnation of nuclear power development, have made critical the issue as to whether energy can be made available, in its desired forms, to meet future demands without sacrificing the environment.

Today raw coal is cleaned to remove as much non-carbonaceous material as is economically feasible in order to produce a uniform high-quality feedstock for any desired use. Some of the reasons for coal preparation are:

- removal of substantial quantities of sulfur from coal,
- concentration of carbon in the clean coal,
- removal of ash,
- reduction in concentration of trace elements and
- uniform quality of product including ash, moisture and Btu content.

Coals have highly variable characteristics by seam and by geographical location. Coals are prepared by size reduction and sorting, based upon particle size and density, to create uniform products of high calorific content and reduced mineral levels; especially sulfur. However, only the pyritic sulfur fraction of the total sulfur content is amenable to separation by physical processing. This limitation of sulfur reduction to the natural organic sulfur level of a particular coal means that the level of coal quality improvements attainable is varying, being constrained by processing objectives, cost, processing technology and coal characteristics.

The specific ways of preparing coal are of course determined by its end use. Most of the coal produced in this country is consumed either by carbonization--to produce metallurgical and chemical coal--or by combustion--to raise steam for electric power generation, to obtain process heat and steam for manufacturing and mining industries or for space heating. Although many of the same methods are used in evaluating coals for different uses, the problems, bodies of knowledge and approaches associated with carbonization and combustion in each area are sufficiently dissimilar that coal evaluation in each area merits separate discussion.

3.3 METALLURGICAL COKE

Another fuel form, metallurgical coke, is almost universally used in blast furnaces, both in ferrous and non-ferrous smelting. Coke is the hard, condensed residue resulting from the slow combustion of bituminous coal in the absence of air. This process distills and drives off the volatiles and leaves a high-carbon product, i.e., coke.

During decomposition, the coal mass fuses and swells and becomes plastic. The volatile substances driven off during the coking process range from simple gases such as CO, CO_2, H_2O, H_2, N_2, CH_4, H_2S, S_2 and NH_3 to various complex hydrocarbons and other organic compounds, some containing nitrogen and sulfur. Gradually the mass solidifies as the process reaches completion.

The by-product coke oven, as shown in Figure 3-1, is the primary tool for processing coke in the United States. The oven is externally heated and allows for the recovery of the coal gases, coal tar, and other valuable by-products.

Not all coals are suitable for coking purposes and those that are selected must be carefully prepared before carbonization to produce a high quality coke. The main purpose in cleaning coals is to reduce moisture, ash and sulfur content; however, coal is also prepared to obtain a uniform product. This is important because coal often varies in quality in different areas of a mine. By preparing the coal, a blending of the various qualities can be achieved to assure a uniform coke with minimum ash and sulfur content.

When used for metallurgical purposes, the presence of sulfur compounds in the fuel represents a genuine problem. For example, in high or vertical furnace processes a lowering of the sulfur content in coke by 1 percent saves from 18 to 20 percent of the fuel, considerably increasing the efficiency of the metallurgical aggregates and contributing to an improvement in the quality of the metal. Also, sulfur in coal used for metallurgy is apt to contaminate the metal. This holds equally true for several other elements which comprise the ash content of coal such as phosphorous and arsenic.

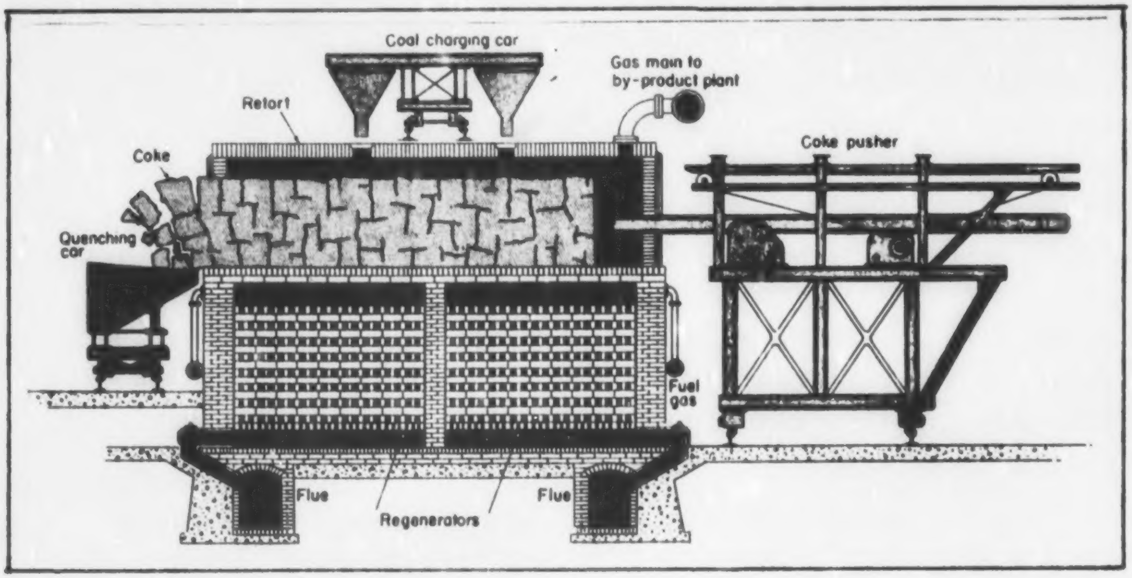

Figure 3-1
By-Product Coke Oven

3.4 STEAM COAL

About two-thirds of the electric energy in the United States is generated by coal-fired plants. Many of these plants use high-sulfur coal although increasingly more stringent Federal, State and local air pollution regulations have intensified the demand for clean fuels and superior control devices.

The major problem of coal-burning power plants is reducing the air pollutants in stack gases. In most of these plants, a chief pollutant is sulfur dioxide from the combustion of organic sulfur compounds present in the coal. Stack gas cleaning systems are expensive to install and operate, and in some cases would not be needed if most of the pollutants were removed from the coal prior to combustion.

The sulfur dioxide standards now applicable to the power industry include Federal regulations which primarily relate to new facilities and those imposed by the individual State Implementation Plans (SIP's). These regulations apply to steam generating facilities which were started or modified after August 17, 1971, within 180 days of the time they came on-line. They apply to all facilities having more than 250 million Btu/hour input (about 10 tons of coal). Besides the maximum 2 hour average value of 1.2 pounds SO_2 per million Btu fired, corresponding values for particulate matter are 1.0 pound and no greater than 20% opacity, and for nitrogen oxides, 0.7 pounds per million Btu fired.

Estimates made in accordance with Project Independence (the President's plan for the United States to be energy self-sufficient by 1985) call for the demand of coal to expand to between 1.2 and 1.7 billion tons per year by 1985. About 94 billion tons of naturally occurring low sulfur coal can be foreseen as a supply that meets air quality regulations. The remaining portion will have to be regulated by using control devices or by coal preparation.

Available methods for controlling sulfur oxide emissions from stationary combustion sources fall into the following major categories:

- the physical removal of pyritic sulfur by physical coal cleaning prior to combustion,
- the scrubbing of sulfur oxides from the combustion flue gas and
- the conversion of coal to a clean fuel by such processes as gasification, liquifaction and chemical extraction.

Of these methods, physical removal of pyritic sulfur is the least expensive and the most highly developed method. The degree of sulfur reduction possible depends upon the characteristics of the raw coal and its amenability to sulfur release upon crushing. These characteristics are unique to specific coals and vary from coal to coal. Until such time as new coal conversion technology becomes available and economical, most sulfur oxide emission control will be affected by physical coal cleaning, flue gas scrubbing or a combination of both.

Additionally, the use of coal in coal fired plants with high ash content results in a greater loss of efficiency, yields a greater amount of ash and leads to greater losses in the flue gases. Also, the loss of sensible heat and combustible matter in the ash is greater and the cost of drying is correspondingly increased.

With the exception of coal used by some stokers or wet bottom furnaces, coal used in utility power plants is normally pulverized. The cost of grinding and the wear and tear of the pulverizers are disproportionately increased if the coal has a high ash content because the shale is harder to grind than the coal. Furthermore, the mineral matter in the dust entering the combustion chamber must be heated to the flame temperature without contributing anything to the heating and the incombustible dust must be discharged from the furnace. The flue gases generally carry large quantities of incombustible dust which is either discharged through the stack or accumulates on the stack walls.

Other than poor design or operation, the quality of the coal greatly effects the efficiency of the combustor. In addition to the operational costs and problems, the increased transportation costs (transporting moisture and other impurities) and the increased disposal cost of the ash add considerable emphasis to the merits of clean coal.

3.5 SUMMARY

Coal is used in sintering, pelletizing, zinc retort smelting, blast furnace smelting and other metallurgical processes. For these processes, special coals prepared to rigid specifications are used to get the desired metallurgical results at lowest cost. By far the largest application is in the form of coke for the iron blast furnace.

Coal is also becoming the primary fuel for steam generation for electric utilities. The mechanical coal cleaning process will allow certain coals to be combusted without additional sulfur emission controls and in those situations where such controls are still necessary, prior coal cleaning helps reduce the emission control costs.

For whatever purpose coal or coke is used, it is to the advantage of the consumer that the fuel should contain the minimum amount of ash. Incombustible material in the fuel reduces its gross calorific value, increases the weight that must be handled and transported, gives rise to difficulties of combustion and involves further expense in its disposal. Also, ash in coal increases the production of smoke and results in the discharge of fine dust from chimney stacks, especially from the stacks of pulverized fuel boilers.

It is clear that with an increasing electric load generated by coal, the emission of SO_2 into the atmosphere must be kept at an acceptable level. There have, however, been difficulties in perfecting SO_2 clean-up systems and processes. Most estimates indicate that these processes will not reach widespread commercial usefulness before the mid-1980's because of chemical and mechanical problems. This fact, coupled with the need to meet stringent air quality standards passed by the Federal Government, provide the rationale for preparing raw coal to remove as much pyritic sulfur as possible before firing.

Clean coal's greatest applicability is to: (1) installations which are not able to use flue gas desulfurization, such as industrial boilers of small size, and (2) existing combustors which require clean coal to meet State Implementation Plans (SIP's).

REFERENCES AND/OR ADDITIONAL READING

Agarwal, J.C.; Giberti, R.A.; Irminger, P.F.; Petrovic, L.J.; & Sareen, S.S., "Chemical Desulfurization of Coal", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Allison, Ira S.; Black, R.F.; Dennison, J.J.; Fahnestock, R.K.; & White, S.M., "Geology: The Science of a Changing Earth" (6th Ed.), McGraw-Hill Book Company, New York, 1974

Bailey, Ralph E., "Coal Industry Overview", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania May 1975

Barlow, James A., "Coal & Coal Mining in West Virginia", Coal Geology Bulletin No. 2, February 1974

Battelle-Columbus, "SO_2 Control: Low-Sulfur Coal Still the Best Way", Power Engineering, November 1973

Brobst, Donald A. & Pratt, Walden P. (Editors), "United States Mineral Resources", Geological Survey Professional Paper 820, U.S. Government Printing Office, 1973

Cutler, Stanley, "Emissions from Coal-Fired Power Plants", U.S. Department of Health, Education and Welfare, 1976

Dopples, Edward C.; Hopkins, M.E. (Editors), "Environments of Coal Deposition (Special Paper #114)", Geological Society of American Symposium, Miami Beach, Florida, 1964 (Edited in Bouton, Colorado, 1969)

Engdall, R.B., "A Critical Review of Regulations for the Control of Sulfur Oxide Emissions", Battelle Columbus Laboratories, APCA Journal, Vol. 23, #5, May 1973

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Jimeson, R.M.; Spindt, R.S., "Pollution Control and Energy Needs", Advances in Chemistry Series, American Chemical Society, Washington, D.C., 1973

Journal of the Air Pollution Control Association, "Panel Calls Beneficiation-FGD Combination 'Most Economical, Best All-Around Choice'", November, 1975

Lawrence, William F.; Cockrell, Charles F.; Muter, Richard, "Power Plant Emissions Control", Mining Congress Journal, April 1972

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Schaeffer, Stratton C.; Jones, John W., "Coal Preparation vs. Stack Gas Scrubbing to Meet So_2 Emission Regulations", NCA/BCR Coal Conference and Expo II, October 1975

Soderberg, H.E., "Environmental Energy & Economic Considerations in Particulate Control", American Mining Congress Coal Convention, May 5-8, 1974

4. THE PREPARATION PROCESS

4.1 OVERVIEW

The coals of the United States have highly variable characteristics by seam and by geographic location. Since coals vary so widely, coal cleaning processes are typically engineered for each coal source and designed with respect to the use to be made of the coal. There is a considerable process uniformity among plants, but each plant is usually individually designed.

Coals are prepared by size reduction and subsequent particle sorting based upon particle size and density. The level of coal quality improvements attainable is variable, being constrained by processing objectives, cost, processing technology and coal characteristics.

For years, preparation plants were designed to produce multiple sizes of coal for various customers, such as lump, egg, stove, stoker and nut sizes. Today, however, plants are designed to produce only one product of definitive characteristics for one specific customer. The preparation plant is designed to remove the non-combustibles from the coal at the minimum practical operating cost and at the optimum practical yield. However, the ROM coal is prepared only to the extent that is necessary to make the product salable.

The range of coal cleaning processes now being practiced in the United States may be generalized into four

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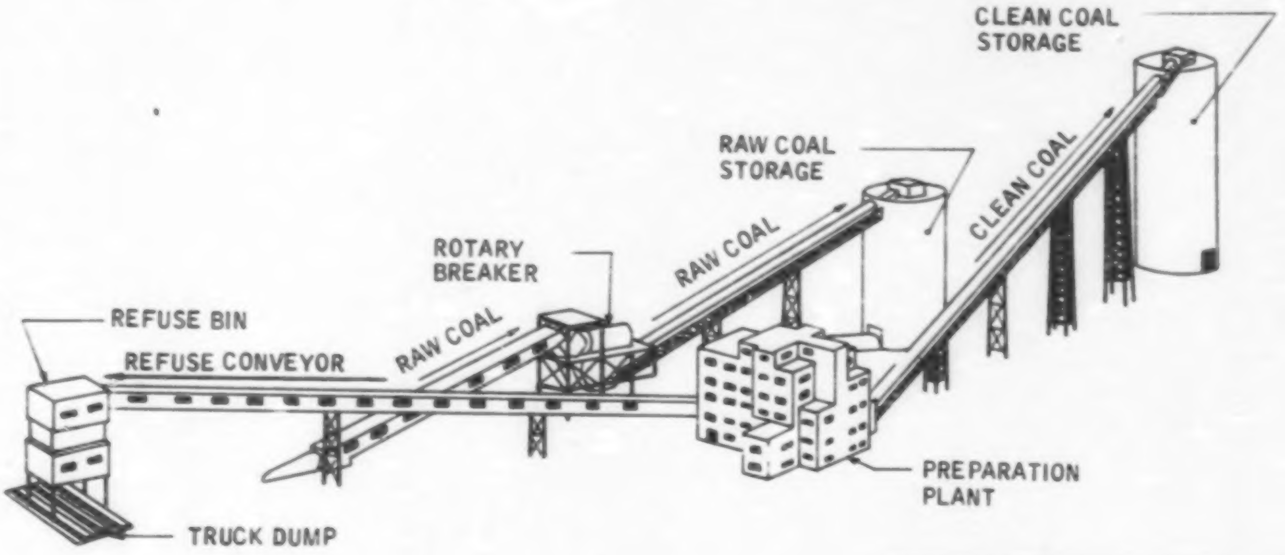
individual levels of preparation. These levels may be defined as follows:

- Level 1--no preparation, direct utilization of the run-of-the-mine product.
- Level 2--removal of gross non-combustible impurities, plus control of particle size and promotion of uniformity (typically 95% material yield and 99% thermal recovery). Little change in sulfur content.
- Level 3--single-stage cleaning allowing little component liberation. Particle sizes less than 3/8 inch usually are not prepared. 80% material yield and 95% thermal recovery. Limited ash and sulfur content.
- Level 4--multi-stage cleaning with controlled pyrite liberation. Usually incorporated dewatering and thermal drying. 70% material yield and 90% thermal yield. Maximum ash-sulfur rejection, and calorific content of product.

Preparation practice for most coals used by electric utilities lies between levels 2 and 3. The preparation practices for metallurgical coals are typically level 4. The relative costs of these different levels are indicated in Table 4-1. The extent to which a specific coal can be cleaned is dependent upon the characteristics of the coal and the sophistication of the preparation process. The limitations are often both economic and technical.

The technical limitations of the preparation process relate primarily to the very small component particles existing in coal. Many of these particles are residual structures of vegetation and minerals, generally irregular in shape. The pyrite particles in many coals are less than 1 micron (0.0004 inch) in their longest dimension. Particles smaller than 50 microns cannot be practically separated from each other, and separating them is usually inefficient. Larger particles, or those less homogeneous in composition, respond more readily to separation.



J. J. DAVIS
ASSOCIATES

The Modern
Preparation Plant

Figure 4-1 DCN

TABLE 4-1

PREPARATION PLANT CAPITAL AND OPERATING COSTS[1]

Eastern Bituminous Coal			
Design Capacity Clean Coal Tons/Yr	Level 4	Level 3	Level 2
3,000,000	$25,200,000	$11,200,000	$3,200,000
2,000,000	17,500,000	8,100,000	2,500,000
1,000,000	9,000,000	4,350,000	1,500,000
Western Subbituminous Utility Coal[2]			
10,000,000			6,720,000
5,000,000			3,360,000
3,000,000			2,040,000
2,000,000			1,580,000
1,000,000			1,200,000
Cleaning Cost $/Ton[5]	0.80[3]	0.45[3]	0.05[3]
	1.74[4]	0.87[4]	0.17[4]
			0.05[6]
			0.12[6]

---

[1] Mid-1974 dollars
Level 4 - Detailed, elaborate facility (75% recovery).
Level 3 - Removal of liberated mineral matter (75% recovery).
Level 2 - Removal of only gross mineral matter (95% recovery).

[2] Only Level 1 or 2 is applicable. Lignite - Level 1 only considered necessary.

[3] Includes labor, power, maintenance - no amortization or return on investment. Thermal drying adds about 25% to capital costs and 30% to operating costs.

[4] Includes straight line financing at 8% interest, 20 years life and 5% ROI.

[5] Eastern Bituminous coal cleaning - three million ton per year.

[6] Western Subbituminous coal cleaning - ten million ton per year at Level 2.

[7] The capital costs utilized for cleaning eastern bituminous coals at Level 4 ranged between $23,000 and $25,000 per ton of raw feed capacity per hour. Utilizing the "Best Practice" cited in Table 4-2 would increase this value to about $30,000 per ton of raw feed capacity per hour. The value would increase to an estimated $40,000 per ton hour if the "best Cleaning Technology Available" were developed.

To be separable, impurity-containing particles must have masses greater than the pure coal particles. The difficulty in separating small size particles (less than 50 microns) results from their slower response to the acceleration of gravity than larger particles; they literally float within the coal. Moreover, since most of the separation is done in water systems, a further complication exists in working with small particles in that removal of the water from them is significantly more difficult and more costly than removing water from the larger-sized particles due to the smaller porosity of the smaller particles or of the combination of particles. Because of the technical difficulty in separating small particles, the separation costs increase as the particle size decreases. The processes which will remove more pyrite from the coal necessarily utilize smaller particle sizes and are considerably more costly. Accordingly, coal cleaned primarily for ash removal is cleaned with as large a particle size as is practical. It is for this reason that coal processing plants which were not designed for sulfur removal often do not function well as pyrite removers.

The economic limitations of coal preparation are varied and numerous. Cleaning of coarse coal is relatively simple and less costly than cleaning of the finer sizes. The fine coal portion in the raw coal feed has materially increased as mechanization of mining process has increased, thus adding considerably to cleaning plant costs. Wet cleaning units for fine coal are not themselves expensive; it is the equipment necessary to dewater and dry the product that adds significantly to the cost. Clarifying the process water and thermal drying substantially increase plant capital investment. Yet many modern cleaning plants must contain this equipment in order to obtain the desired ash, sulfur and moisture in the product and still recover the greatest amount of salable coal.

The disposal of waste refuse developed during the coal cleaning process (CCP) represents an additional cost which must be attributed to the preparation plant. Sample capital and operating costs for several coal refuse disposal operations in Kentucky and Alabama have been developed. In 1969 dollars, these values were about $0.27 per ton of refuse or $0.09 per ton of salable clean coal. To that, an additional cost of about $0.01 per ton of refuse must be added for final disposal site reclamation. These costs do not incorporate any consideration of land values.

The cost of refuse disposal depends upon:

- Distribution between coarse and fine refuse sizes: For example, fine refuse poses similar problems to the disposal of flue gas desulfurization sludge, and poses even more severe potential water pollution problems. Coarse refuse disposal costs about twice that of fine refuse disposal while the latter may require greater land area and more complex engineering. Research continues to develop procedures to convert the fine refuse to more dense and manageable form. Labor and maintenance costs are higher for coarse refuse disposal while power costs are greater for fine disposal when they must be pumped away.
- Distance from preparation plant to disposal area.
- Local topography and land availability for disposal site construction.
- Existing or impending environmental controls.

In addition, coal preparation processes are consumers of energy--they both utilize it in the processing and lose some of it in the rejected refuse. Most energy consumed during coal processing is utilized for one of the following:

- to move the coal components through the cleaning system,
- to create new surface area by breaking or crushing,
- to activate equipment to manipulate the particle separation,
- to remove water from the coal and
- to operate environmental protection systems.

In general, processing energy requirements increase with the beneficiation level and decrease as particle size increases.

Among the factors which may determine the final delivered cost of coal to an electric generating station are:

- the cost of run-of-the-mine coal at the mine portal,
- the cost of cleaning,
- the cost of handling and disposal of preparation plant refuse,
- the level of clean coal yield and thermal recovery,
- the cost of coal storage at the mine, preparation plant and generation station,
- the cost of coal loading at the mine or preparation plant and unloading at the generating station and
- the transportation costs.

Other economic impacts which must be compared between use of run-of-the-mine coal and clean coal are:

- the pulverization costs (power consumed and plant maintenance) and

- the disposal cost of ash developed during coal combustion.

The economic implications of coal preparation are presented in Table 4-2 comparing sample costs for the same coal burned "as mined" and cleaned. The clean coal, with a 0.6% lower cost, on a weight basis is 5.2% higher cost in terms of ¢/MM Btu or mills/KWHr generated. This cost comparison model neglects several factors which are difficult to quantify, but would undoubtedly enhance the value of prepared coal. Among the factors favoring clean coal are:

- greater reliability of power plant performance,
- reduced coal handling costs and storage costs,
- greater heat-release capabilities--boiler capacity design,
- reduced slag-fouling maintenance in boiler and heat transfer systems and
- reduced quantities of fly-ash for collection.

4.2 PREPARATION PLANT MODULES

The physical cleaning of coal may be categorized into five general processes when examined strictly in relation to the preparation plant. These are:

- plant feed preparation,
- raw coal sizing,
- raw coal separation,
- product dewatering and/or drying and
- product storage and shipping.

The sizing, separation and dewatering processes may each be further broken down into three sub-processes which are used for coarse, intermediate or fine sized coal, respectively.

TABLE 4-2

COMPARATIVE COAL COSTS FOR UTILITY CONSUMPTION UTILIZING CLEANED COAL AND RUN-OF-MINE FROM THE SAME MINE

BASIS: 1 TON CLEANED COAL

	Prepared Coal[2]	Run-of-Mine Coal
Value at shipping point		
$ expression	14.46	13.31[3]
¢/MM Btu	52.20	45.30
mils/KWhr	5.35	4.64
Value at Utility (Includes Transportation)[5]		
$ expression	18.25	17.86
¢/MM Btu	65.90	60.70
mils/KWhr	6.76	6.23
Value as fired (includes coal grinding costs)[6]		
$ expression	18.38	18.14
¢/MM Btu	66.40	61.70
mils/KWhr	6.80	6.33
Total fuel costs at utility (includes ash disposal)[7]		
$ expression	18.62	18.73
¢/MM Btu	67.20	63.70
mils/KWhr	6.89	6.53

Basis for Comparative Cost Calculations

Coal Data	
Clean Coal Yield	83.20%
Thermal loss in cleaning	5.85%
Heat Content (Btu/lb)	
Run-of-Mine	12,240
Clean Coal	13,850
% increase	13.20
Ash Content (Wt. %)	
Run-of-Mine	16.40
Cleaned coal	7.90
% decrease	51.80

TABLE 4-2 (Continued)

COMPARATIVE COAL COSTS FOR UTILITY CONSUMPTION UTILIZING

CLEANED COAL AND RUN-OF-MINE FROM THE SAME MINE

1. Based on Central Pennsylvania low volatile bituminous coal. Assessed at $14.46/T based on average U.S. selling price for utility coal, May 1974. This price was equivalent to 65.8¢/MM Btu, and represents an average calorific content of 11,000 Btu/lb SOURCE: Federal Power Commission Data. Coal News. No. 4226, 1/14/74. National Coal Association, Washington D.C. It is further assumed for this example that the figure of $14.46/T includes $1.80/T contribution to the UMWA Royalty Fund.

2. Assumed cleaning cost $1.50/T of clean coal. A constant moisture content of run-of-mine and cleaned coal is assumed.

3. Value of run-of-mine coal $9.28/T. 1.20 tons required to prepare 1.00 ton of clean coal. Upon direct sale of the run-of-mine product, the $1.80/T UMWA Royalty would be added.

4. 1971 U.S. average for coal: 10,252 Btu used to generate 1 KWhr.

5. Assumed shipping cost $3.79/Ton (for 1973). SOURCE: Coal Traffic Annual, 1974 edition, p. 27. National Coal Association, Washington D.C. The cost advantages of storage and handling 20% less coal in cleaned form at the power station have not been included.

6. The grinding of coal for pulverized firing to 70% minus 200 mesh requires energy consumption which varies with coal hardness. Hardness is usually expressed as Hardgrove Grindability Index. A 55 HGI coal uses 7.9 KWhr/T, while a 100 HGI coal uses 4.4 KWhr/T. For these calculations power was charged at 3 cents per KWhr. The value for the softer coal was utilized for clean coal while the harder coal value was used for run-of-mine coal. SOURCE: Private communication - Mr. Richard Borio. Combustion Engineering, Inc. Windsor, Conn. February, 1975.

7. Calculations based upon $3.00/Ton for ash disposal at the utility.

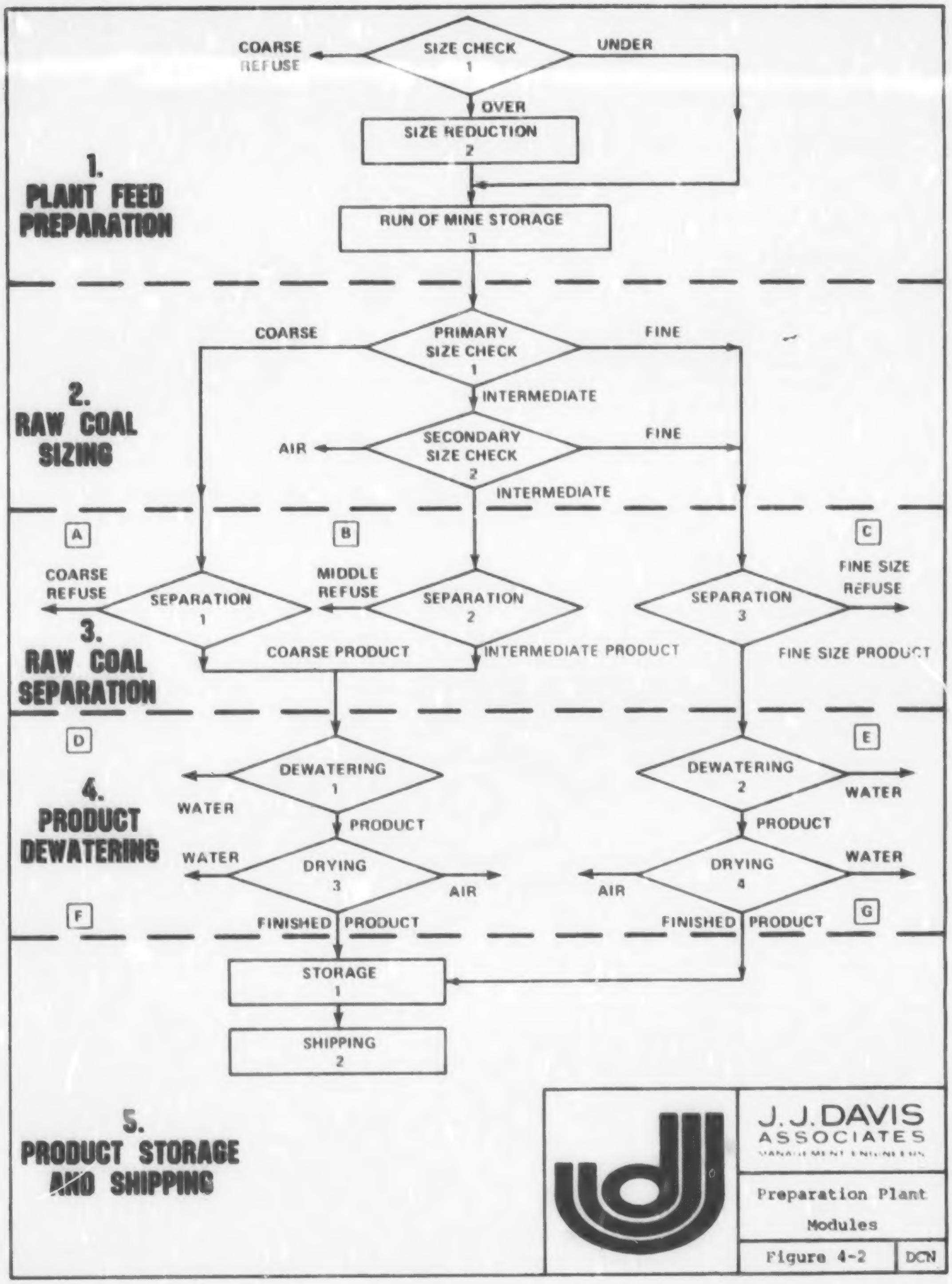
Source of Table: Lovell, Harold L., Sulfur Reduction Technologies in Coal by Mechanical Beneficiation (Third Draft), Pennsylvania State University, March 5, 1975.

The preparation plant module diagram, Figure 4.2, graphically portrays the major module categories. In addition, this chart shows the main refuse streams at their points of origin. The individual processes may be defined in the following manner:

- Plant feed preparation--This process is primarily an initial size check, an initial size reduction and the storage of the raw coal. The raw coal storage may be either open or closed. Open storage typically refers to piles of coal stored upon the ground (usually conical). Closed storage refers primarily to raw coal that has been stored in a closed silo, generally from 2,000 to 5,000 tons capacity. The initial separation and reduction is normally performed by a rotary-type breaker which separates ROM only as being over six inches or under six inches. Any product that is over six inches and passes the breaker is directed immediately to the coarse refuse disposal pile. All other product is impact reduced by the breaker and fed directly to the preparation plant or to the storage area.

- Raw coal sizing--Raw coal sizing typically consists of a primary size check and a secondary size check which separates the coal into coarse, intermediate or fine sizes. Primary sizing is usually accomplished by a raw coal screen or a scalping deck which separates the coal into coarse or intermediate sizes. The coarse product is reduced in size as necessary (usually 2" or 1 1/4" x 0), and returned to the sizing operation. A secondary size check which is either a wet or dry vibrating screen separates the intermediate sizes from the fines and directs the product to module three - raw coal separation.

- Raw coal separation--This process works with the coarse, intermediate or fine sizes, and has unique separation processes suited to the three individual size groupings. Most of these processes are based upon gravity separation of the coal from the unwanted impurities. After separation, the products are directed to module four - product dewatering.



J. J. DAVIS ASSOCIATES
MANAGEMENT ENGINEERS

Preparation Plant Modules

Figure 4-2 DCN

- Product dewatering and/or drying--This includes dewatering and drying of the coarse and intermediate sizes and an individual dewatering, possibly with a thermal drying process, for the fines.
- Product storage and shipping--This includes storage, handling and shipping operations and may take a variety of forms.

The level of detail for any individual module is variable and directly dependent upon the number and the degree of complexity of the individual components that comprise the operating tools. For example, plant feed and initial product sizing are usually straightforward operations (operationally and from the potential for environmental impact and the ease of environmental control). However, product separation is extremely variable in regard to the number of possible combinations of equipment, the influence of the specific coals, refuse or by-product generation, etc. Therefore, within the product separation module, the level of detail of module or sub-module development may be considerable. Each of the process modules will be discussed in separate chapters.

As with any operation involving man, materials and machinery, there are a multitude of individual units or combinations of units available to perform any specific operation or task. For the purposes of the manual only those units or combinations of units that are most typical will be discussed; esoteric units will be discussed only where their uniqueness or future benefit to the coal cleaning process merit special attention.

REFERENCES AND/OR ADDITIONAL READING

Bituminous Coal Research, Inc., "An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal", BCR Report L-339, September 1969, BCR Report L-362, February 1970, BCR Report L-404, April 1971, BCR Report L-464, April 1972

Carta, M.; Del Fa, C.; Ciccu, R.; Curreli, L.; Agus, M., "Technical and Economical Problems Connected with the Dry Cleaning of Raw Coal and in Particular With Pyrite Removal by Means of Electrical Separation", Italy, Australian Coal Conference

Coal Age, "Coal Preparation and Unit-Train Loading", July 1972

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Foreman, William E., "Impact of Higher Ecological Costs and Benefits on Surface Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Gospodarka, Gornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Grimm, Bobby M., "Preparation Plant Corrosion Cost", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Hill, George R., "Clean Fuels from Coal--The OCR Challenge", Mining Congress Journal, February 1973

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jenkinson, D.C., "Some New Coal Preparation Developments in the United Kingdom", National Coal Board Bulletin M4-B148

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Johakin, J., "Solving the SO_2 Problem--Where We Stand with Application and Costs", Coal Age, May 1975

Katen, Ken P.; Palowitch, Eugene R., "Shortwall vs Conventional Systems", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May, 1975

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

Kuti, Joe, "Longwall vs. Shortwall Systems", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Llewellyn, Robert L., "Coal Preparation", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York, 1968

Lotz, Charles W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Lovell, Harold L., "Sulfur Reduction Technologies in Coal by Mechanical Beneficiation (3d Draft)", Commerce Technical Advisory Board Panel on SO_2 Control Technologies, March 1975

McNally-Pittsburg Manufacturing Corporation, "Coal Cleaning Plant Prototype Plant Design Drawings", Department of Health, Education and Welfare Contract 22-68-59

McNally-Pittsburg Manufacturing Corporation, "Coal Preparation Manual #572", Extensive Analysis on McNally-Pittsburg Coal Cleaning Technology

Roberts & Schaefer Company, "Manufacturers Information Booklets", Chicago, Illinois

Roberts & Schaefer Company, "Design & Cost Analysis Study for Prototype Coal Cleaning Plant", August 1969

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant", January 1973

U.S. Bureau of Mines, "Clean Energy from Coal Technology", Overview of Coal/Energy Usage, U.S. Government Printing Office, 1974

5. PLANT FEED PREPARATION AND RAW COAL STORAGE

5.1 OVERVIEW

The plant feed preparation and raw coal storage module consists of an initial size check, initial size reduction and storage of the raw coal before it is fed to the preparation plant. This module is highlighted in Figure 5-1.

The first step in the coal cleaning process is the delivery of the run-of-the-mine (ROM) coal to the plant site. The coal may be delivered in railroad cars from distant mines, by trucks from the strip pits or by conveyors or mine cars from the working faces in underground mines. The equipment for raw coal handling starts underground at the mining headhouse or at the truck dump at surface mines. For example, some underground mining sections have surge feeders which are equipped with breakers to reduce the top size of the coal before it is discharged onto the conveyor belt or into the mine cars, and the truck dump itself at some surface mines may serve to reduce the initial size of the ROM coal either from impact breakage or crushing by the weight of the coal pile.

We will not address at this point the transportation of the ROM coal to the plant site; however, it is important to recognize in the preparation plant design the condition of the coal as it comes from the mine.

5.2 INITIAL SIZE CHECK

ROM coal may contain very large pieces of rock, wood or other impurities as well as coal. The method of mining

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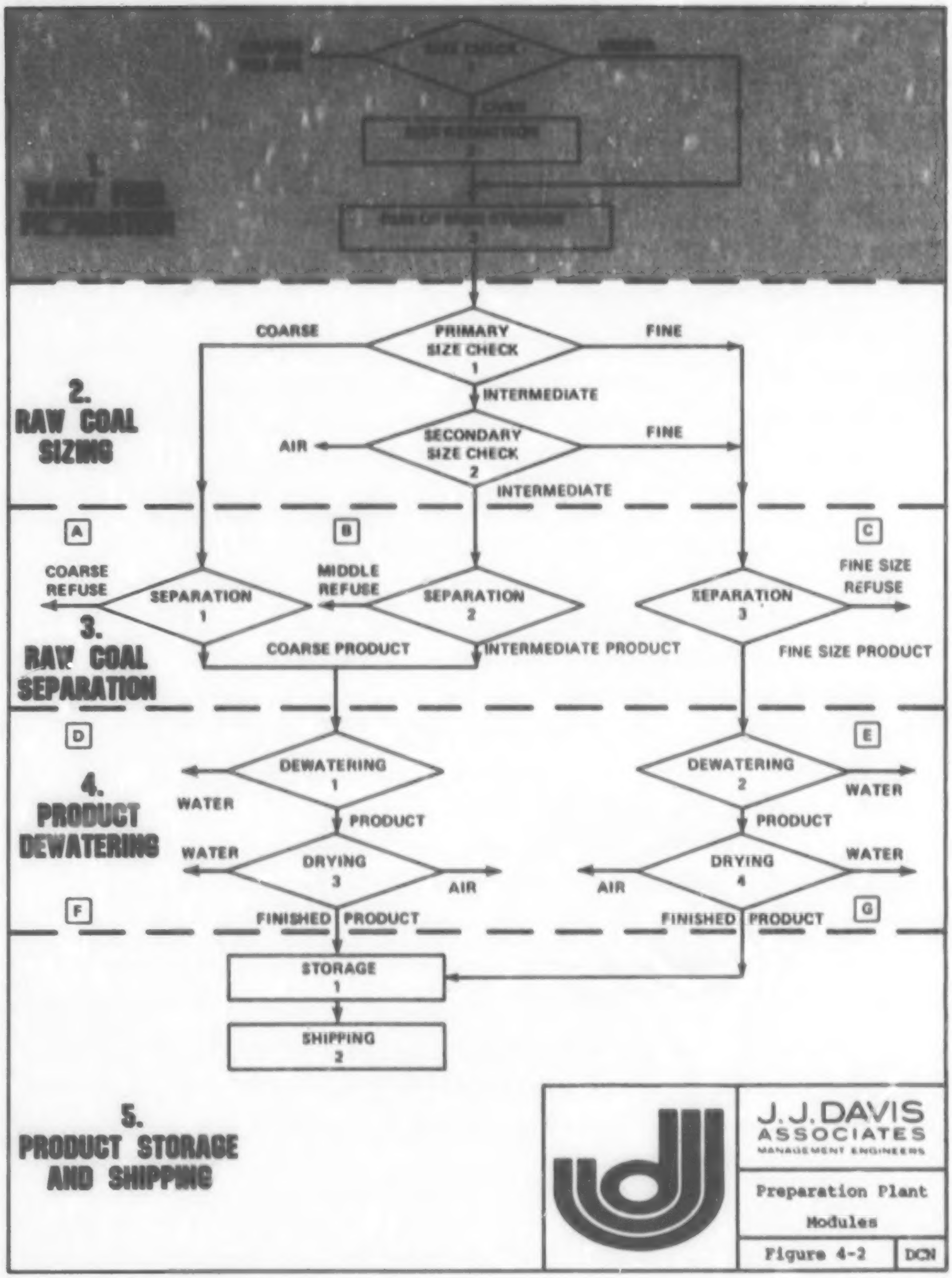


Preparation Plant Modules

Figure 4-2

has a major effect upon both the size consist and amount of impurities found in the ROM coal. Where conventional mining is still used, there will be a high percentage of large coal lumps, but very little rock. Where mechanical full-seam mining is used, large pieces of rock may accompany the coal. However, continuous mining machines tend to create more coal fines.

When the ROM coal is delivered to the preparation plant site, it is dumped into a surge bin or surge feeder which controls the feed through the first process module. Usually the first piece of equipment actually belonging to the preparation plant that the ROM coal contacts is the run-of-the-mine scalper.

The ROM scalper is aptly named. It literally scalps the large pieces of coal and rock off the top of the ROM coal feed as shown graphically in Figure 5-2. The purpose of the scalping screen is to size the ROM coal prior to the primary, or initial, crushing operation. The scalper helps reduce wear on the primary crusher by allowing the finer coal and waste material to bypass the crusher; it improves belt conveyor life by allowing a bed of fine material to be placed on the belt prior to the larger lumps, and it allows for the use of a smaller crusher because of the reduced tonnage which is being fed to it (see Figure 5-2).

As noted in Chapter 2, the abrasiveness of coal is a major problem which must be dealt with during the coal cleaning operation. By eliminating the quantity of fine material entering the primary breaker and by providing an impact bed on the conveyor, the ROM scalping screen greatly assists in prolonging the life of the equipment involved in the first module.

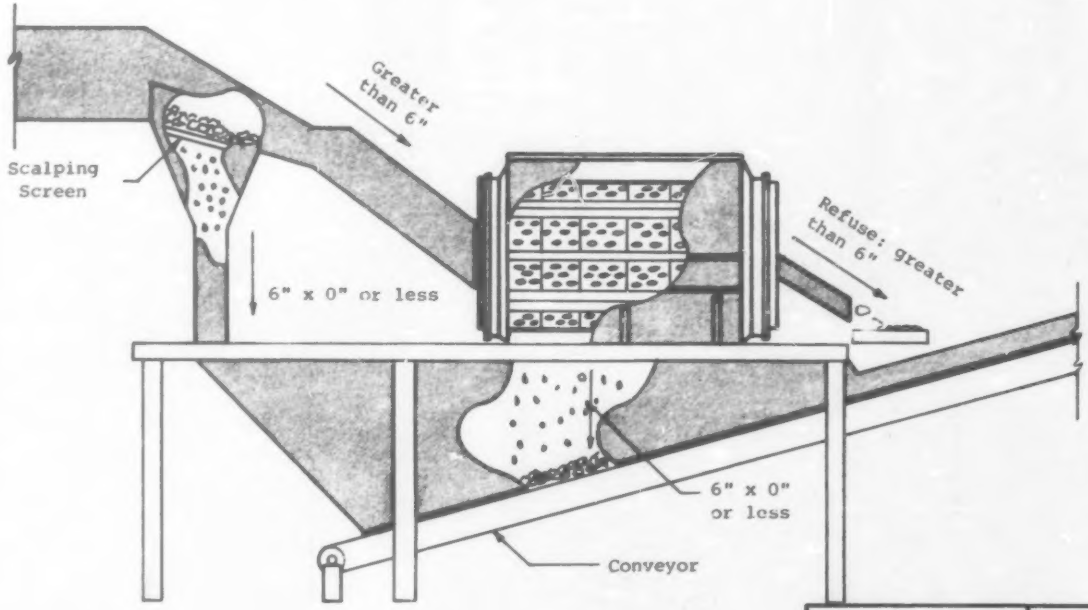
The ROM scalping screen may be fixed or vibrating. It is usually installed with a slope between 20 and 35 degrees. The slope of the screen dictates its capacity. An increase in slope of the screen will increase the velocity of the material passing over the screen and hence increase its capacity while reducing its efficiency. The scalping screen is necessarily of very heavy duty construction enabling it to handle the large tonnages of coal and rock involved (up to 1500 tph). The screens are designed with the length twice the width to allow sufficient time for the majority of the smaller material (usually 6 inches x 0) to fall through the screen openings onto the conveyor belt. In some cases, lightweight wire mesh or canvas type material is installed over the screen flow to slow the flow and allow more of the smaller material material to fall through the openings. However, since the oversize (that material passing over the screen) is crushed, sizing efficiency is of secondary importance.

5.2.1 Fixed ROM Coal Screen

If the scalping screen is fixed, it is generally referred to as a bar screen or grizzly. This is the simplest type of screening device found in the coal preparation plant. The grizzly consists of equally spaced parallel bars made of cast or forged alloy steel installed parallel to the feed flow and inclined about 30 degrees. The grizzly works well with a relatively dry, non-sticky ROM coal feed.

5.2.2 Vibrating ROM Coal Screen

If the characteristics of the ROM coal are other than dry and non-sticky, it is usually necessary to install a vibrating type ROM coal screen. The vibrating ROM coal screen is usually installed at 25 degrees of slope, and



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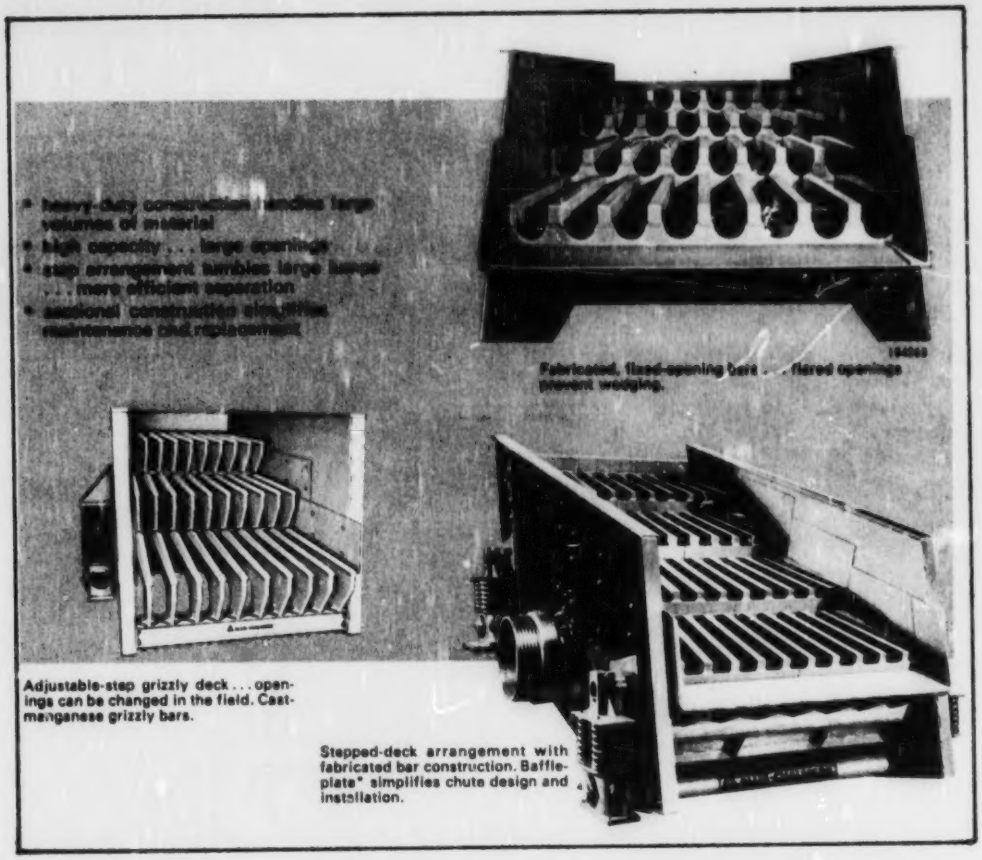
ROTARY BREAKER

Figure 5-2

DCN



- heavy-duty construction handles large volumes of material
- high capacity . . . large openings
- step arrangement tumbles large lumps . . . more efficient separation
- sectional construction simplifies maintenance and replacement

Fabricated, fixed-opening bars . . . flared openings prevent wedging.

Adjustable-step grizzly deck . . . openings can be changed in the field. Cast-manganese grizzly bars.

Stepped-deck arrangement with fabricated bar construction. Baffleplate* simplifies chute design and installation.

Figure 5-3

Bar Screens or "Grizzly"

Source: Allis-Chalmers

has a single, perforated plate deck with an impact section built into the feed end to absorb the impact of the large pieces of rock and coal. Skid bars to assist the large pieces in their journey are usually located at the feed end of the screen and, in some cases, over the entire screen deck depending upon the size consist and abrasiveness of the ROM coal. The deck openings normally range from 4 to 8 inches with the norm being 8 inches. The scalper operates with a relatively large stroke (½ inch) because of the large openings. The ½-inch stroke will generally prevent the sticky clay or wet coal from adhering to and clogging the screen deck. Figure 5-4 depicts a large vibrating ROM coal screen.

5.3 INITIAL SIZE REDUCTION

There are two primary objectives in crushing coal. One is to reduce the run-of-the-mine coal to sizes suitable for cleaning or further reduction; the other is to reduce the coal to market size. The second step in the plant feed preparation and raw coal storage module is the reduction of the ROM coal to make it suitable for cleaning.

There are many types of crushers available, but for any particular job one specific type of crusher will probably perform better than any other. The problem is to determine the one crusher that will give the desired product in the capacity required at the lowest cost per ton. The selection of the proper type of crushing facility depends in part upon the following considerations:

- maximum size of the feed coal,
- desired capacity,
- desired product size,
- friability of the coal,

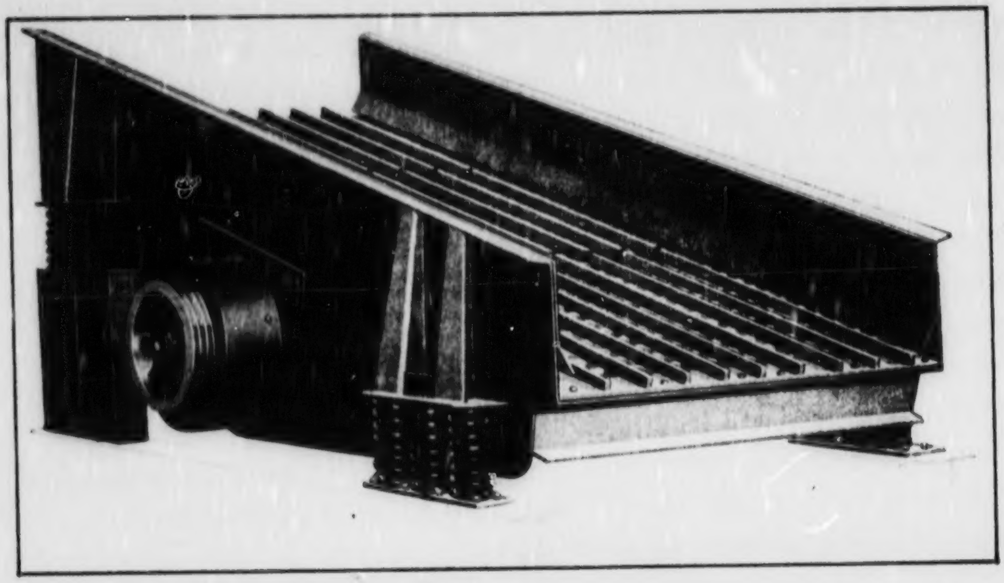
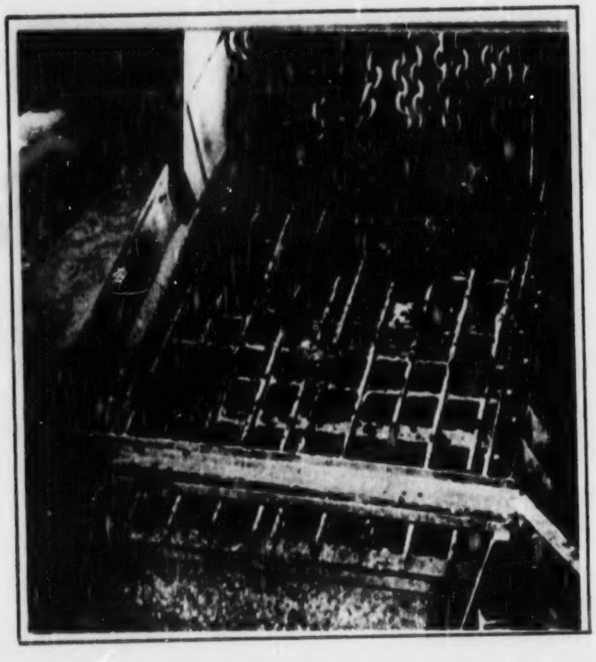


Figure 5-4
Vibrating ROM Coal Screens



- presence and percentages of rock, sulfur balls, clay, etc.,
- quality of resulting fines and
- moisture content of the feed coal.

The maximum input size, the desired product size and the capacity desired are all engineering characteristics which are important to equipment selection and are self-explanatory. The friability and moisture content of the coal as well as the presence and percentages of rock, sulfur balls and clay as important criteria for equipment selection require further discussion.

The friability of the coal not only contributes to the existing state of the ROM coal, but also denotes the ease with which the coal may be further reduced, i.e., whether the coal may be easily impact reduced or whether the coal must be crushed in a roll-type or other type of crusher.

The presence, nature and quality (usually expressed in percentages) of impurities play an important role in equipment selection as well. The size, relative hardness and percentage of rock and sulfur balls when weighed in relation to the friability of the coal may eliminate one type of crusher or another, i.e., the rock may aid in breaking the coal in a Bradford-type rotary breaker and in forcing the coal through the perforated plates in the breaker (see Figure 5-2). On the other hand, if a large percentage of clay is present, and a Bradford-type breaker is used, the entire perforated plate surface may soon be plugged and everything entering the breaker will go directly to the refuse bin. Likewise, if the moisture content of the ROM coal feed is too high, the wet fines may plug the perforated plate in the Bradford-type breaker, or they could literally jam a roll crusher.

5.3.1 Rotary Breaker

The rotary breaker is a heavy trommel screen having lifters on the inside. The rotary breaker actually serves a dual purpose in that it both reduces the size of larger pieces and removes coarse refuse and tramp iron. The use of this breaker is specifically confined to ROM coal. The raw coal feed enters at one end and the undersize quickly passes through the perforations in the outer shell. The lifters continually raise both coal and refuse on the ascending side as the shell revolves. The material slides off the lifters as it reaches the top and falls down onto the bottom, which after a few revolutions will consist of the larger pieces of both coal and refuse. Breaking at this stage is largely due to impact. As the larger pieces are broken down to smaller sizes, they pass through the perforated shell, and only those pieces which are not sufficiently reduced in size pass through the exit end of the breaker and report to the refuse bin. It is important that the ROM coal have a suitable friability index to allow it to be sufficiently broken, while the refuse must be much harder so that it is not broken, thus permitting its discharge from the exit (refuse) end of the breaker.

The rotary breaker has several advantages over other types of breakers (see Section 5.3.2) such as better dust control (Figure 5-5 and 5-6) and the effective elimination of large refuse without the loss of carbon. However, as noted in Section 5.3, there are several limitations to its use. For example, if the feed contains sticky clay, the breaker tends to roll the clay into balls which become pounded into the shell perforations and which will eventually plug up the breaker (at which time the breaker must be stopped and cleaned out, effectively curtailing the operation of the entire plant).

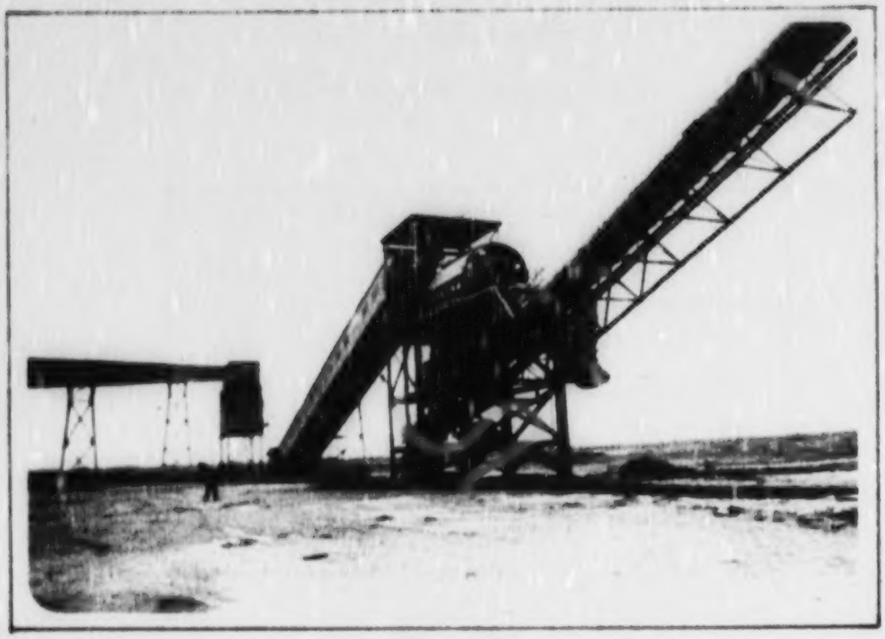


Figure 5-5
ROM "Bradford" Breaker
In A Well-Controlled Environment

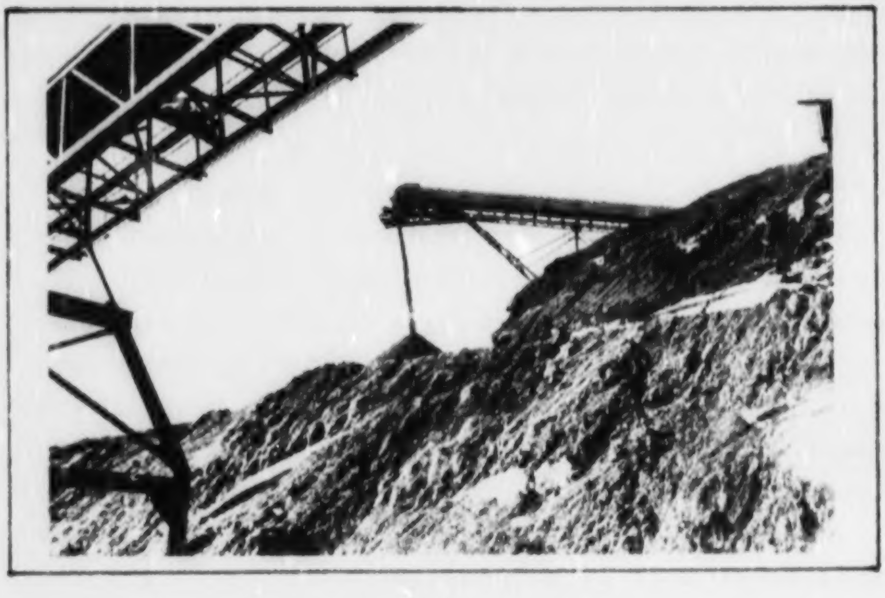


Figure 5-6
Roll Crusher In
Worst Possible Environment

Table 5-1

Sizes and Capacities of Rotary Breakers

Size Diam. x Length, Ft	Motor, Approx. Hp	Capacity Approx. Thp	Type of Coal
6 x 8	10	75- 150	Soft
7 x 14	15- 20	125- 250	Soft
9 x 17	40- 50	275- 450	Medium
10.5 x 19	60- 75	500- 750	Medium or hard
12 x 22	100-150	1,000-1,5000	Hard

5.3.2 Other ROM Coal Crushers

If the rotary breaker is not utilized for the primary size reduction operation, pick breakers, hammermill, ring crushers, jaw crushers, single- and double-roll crushers and two-stage crushers are common types of crushers that have been applied to reduce coal to a smaller size for cleaning purposes.

The usual alternative, however, is a single- or double-roll crusher (mostly double-roll in modern plants). Single- and double-roll crushers are manufactured in various grades, from light-duty models for processing straight coal to heavy-duty models for handling large quantities of rock plus coal. Most models have spring-release mechanisms which enable the crushers to avoid failure when metal pieces such as miner cutting teeth, etc., are encountered in the ROM coal feed. Roll-type crushers break coal by compression (Figures 5-7, 5-8),

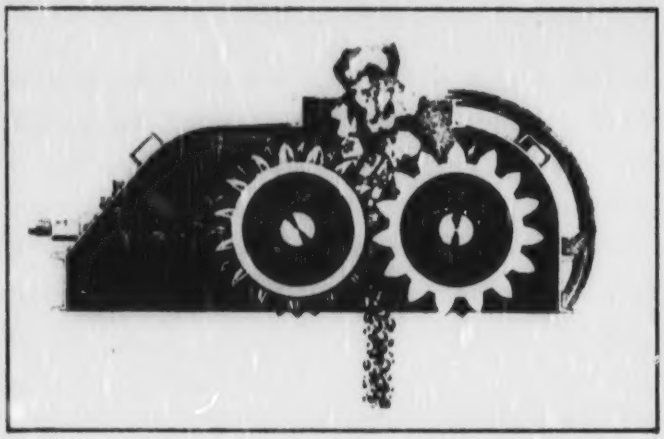


Figure 5-7
Cross section of double-roll crusher

Source: The Jeffrey Manufacturing Company

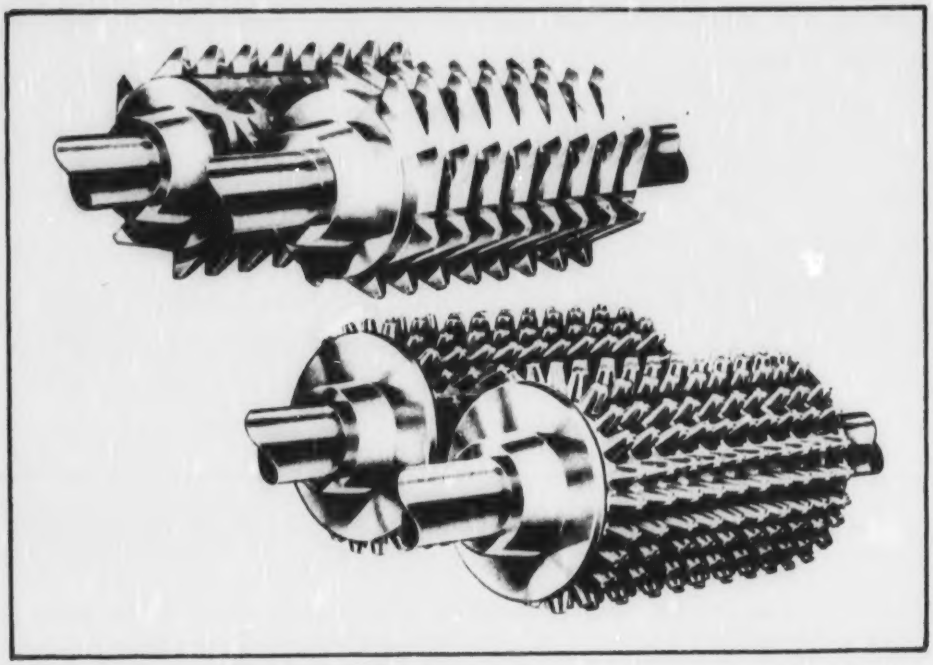


Figure 5-8
Crushing Heads

i.e., a tooth penetrates a piece of coal and splits it into smaller pieces in an action that is similar to that of driving a wedge. The double-roll crusher has several major advantages when used for initial size reduction: it produces a very small amount of fines and it is very adjustable, allowing it to accomodate the varying nature of ROM coal.

Table 5-2

Capacities of Double-Roll Crushers

Roll Size Diam. x Width, In.	Max. Size of Feed, In.	Speed of Rolls RPM	Product Size, In.				Min. Motor Hp
			4	5	6	7½	
			Soft Bituminous Coal				
24 x 36	6-16	130	170	200	270	300	15
30 x 48	8-20	115	250	330	400	450	25
Hp per Ton Crushed			1/3	1/6	1/6		
			Medium Hard Bituminous Coal				
24 x 36	6-18	130	200	260	290	350	15
30 x 48	8-24	115	300	390	460	575	25
Hp per Ton Crushed			1/4	1/8	1/8	1/8	
			Hard Bituminous Coal				
24 x 36	6-20	130	220	290	350	450	15
30 x 48	8-24	115	375	470	550	700	25
Hp per Ton Crushed			1/6	1/10	1/10	1/10	

The other types of crushers mentioned are used occasionally as ROM coal crushers, though typically they are reserved for fine coal crushing. Detailed discussions concerning these crushers, their applicability and the engineering of fine coal crushing are in Chapter 7.

5.4 RAW COAL STORAGE

The third and usually the final step in Module One is the storage of the raw coal. This storage function has become an increasingly important operation in the new, larger preparation facilities for several reasons:

- To limit interruptions of feedstock to the preparation plant, i.e., to allow the mine and the plant to function independently with delays in one not affecting the operation of the other.
- To allow controlled feed to the plant which improves its efficiency--the plant can usually operate at a much faster rate than the mine and the plant should not operate much below its designed operating level to achieve maximum beneficiation of the coal.
- To facilitate blending of various ROM coals to assist in evening out chemical and physical variations which may occur if coal from more than one mine is processed, or if the plant is servicing a very large mine where the characteristics of the coal from various places in the mine vary considerably.

On the other hand, however, several problems are encountered when storing coal for extended periods of time, so that common practice in modern preparation plants is to store only enough raw coal to feed the preparation plant for a four to eight hour period, thus eliminating the major problems. A discussion of coal storage problems appears in detail in Chapter 9.

Storage of the raw coal is generally classified as open storage, closed storage or a combination of both. (Figures 5-9 and 5-10 depict open and enclosed storage facilities.) The selection of the raw coal storage facility is dependent upon a number of factors. Factors of primary importance are:

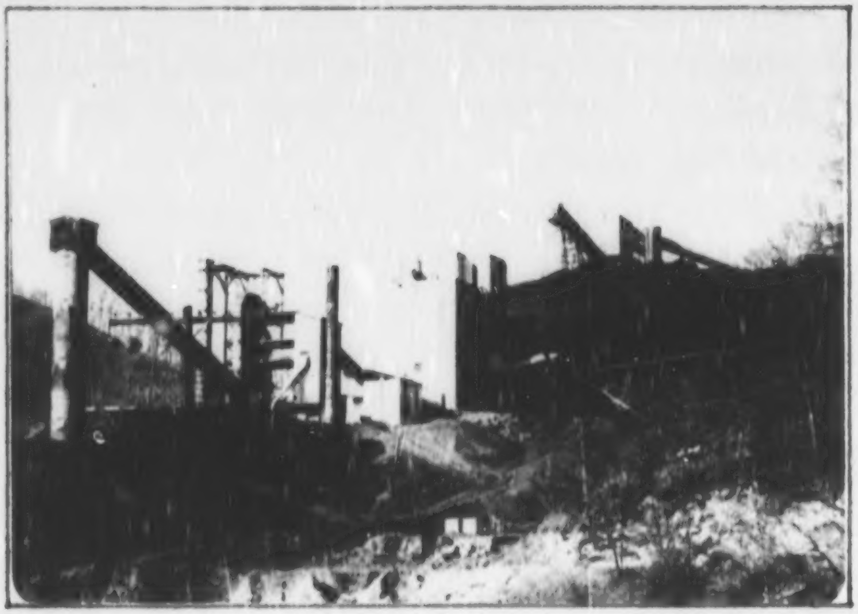


Figure 5-9
Open Raw & Clean Coal Storage

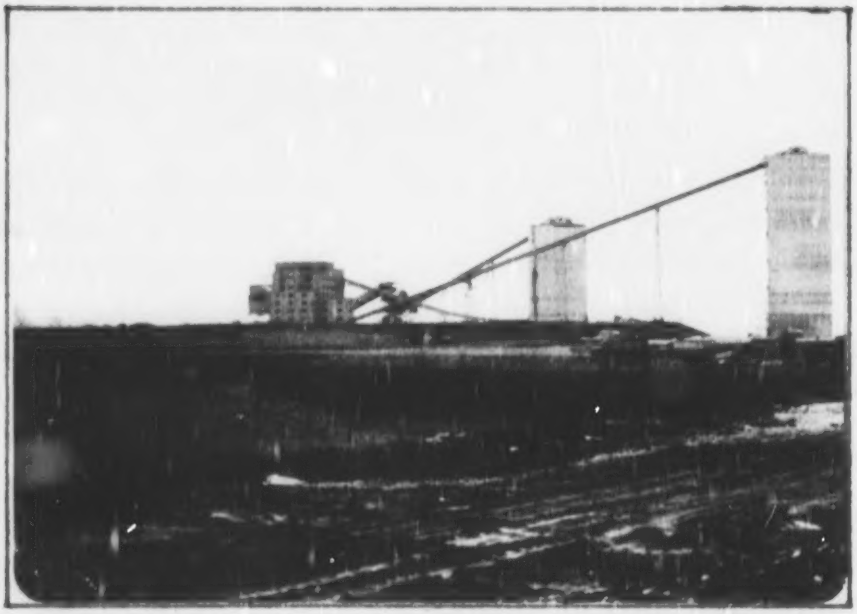


Figure 5-10
Enclosed Raw & Clean Coal Storage

- the plant location in relationship to the mine(s),
- the mode of transport of the ROM coal to the plant site,
- the average weather conditions,
- the plant capacity, etc.,
- the characteristics of the ROM coal and
- the capital investment required.

The plant location in relationship to the mine or mines and the mode of transport of the ROM coal to the plant site play an important role not only in determining whether or not the storage function occurs before the initial size check and size reduction or afterwards as depicted in Figure 5-1, but also in determining the method of storage. For example, if the preparation plant is some distance from the mine and the primary method of haulage of the ROM coal is rail car, the ROM coal will usually be held in the rail cars and processed through the initial size check and size reduction only as needed for feedstock. If, on the other hand, the coal is transported to the plant site by conveyor or truck, it is obvious that major delays will occur in the mining operation if some storage is not provided at the plant site.

The characteristics of the ROM coal, coupled with or independent of the climatic conditions, may dictate the storage facility. If, for example, there are strong, prevailing or persistent winds, as found in some mountainous areas and some parts of the Midwest, it may be impossible to store coal in open storage without serious windage losses and serious air pollution generation in the form of dust. If the coal is very moist and therefore not as subject to windage, but the climate is very wet, serious water pollution in the form of acid runoff may be generated by open, uncontained storage facilities.

If the preparation plant capacity is small, 250 to 600 tons per hour (tph), and if the characteristics of the ROM coal and/or the climate are not too severe, the initial capital investment required to build a closed storage facility may simply be beyond the financial reach of the potential developer.

5.4.1 Open Storage for Raw Coal

Ground storage piles for raw coal are usually conical or wedge-shaped. The conical pile is the simplest form of storage and the one most often selected for raw coal storage. The conical pile is usually flat bottomed with coal in the dead storage area as shown in Figure 5-11 or with an earthfill in the shape of a doughnut (Figure 5-12) which helps to minimize the dead storage area. The ROM coal is usually delivered to the pile via a stacker conveyor which may be equipped with a telescopic chute to minimize dust generation.

Other than the potential pollution problems, the most critical factor in ground storage is the recovery of as much coal as possible with a minimum of expense for equipment and labor. A simple 15,000 ton conical pile with one center opening to the conveyor gallery will deliver only 3,000 tons of coal to the plant (this is called "live" storage). The other 12,000 tons are "dead" coal and would have to be bulldozed to the feeder opening to be recovered. By extending the conveyor tunnel across the diameter of the pile and providing a multi-feeder arrangement, 50% to 60% of the coal becomes live storage.

The problems of obtaining maximum, open, live storage of the raw coal is reduced in a few of the very

Figure 5-11

Conical Pile and Dead Storage

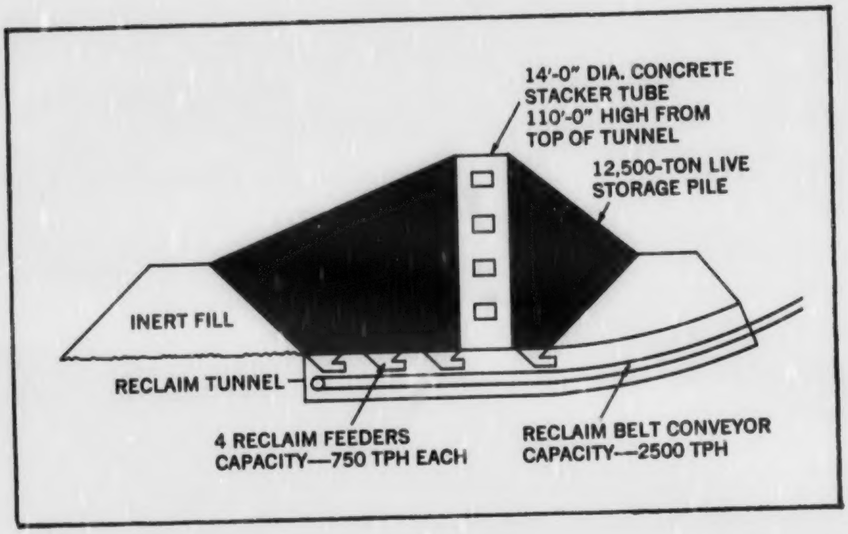

14'-0" DIA. CONCRETE STACKER TUBE 110'-0" HIGH FROM TOP OF TUNNEL
12,500-TON LIVE STORAGE PILE
INERT FILL
RECLAIM TUNNEL
4 RECLAIM FEEDERS CAPACITY—750 TPH EACH
RECLAIM BELT CONVEYOR CAPACITY—2500 TPH

Figure 5-12

Conical Pile with Earth Fill
to Eliminate Dead Storage

large preparation plants by using wedge-shaped piles ranging from 25,000 tons to 100,000 tons of total storage. However, this type of raw coal storage is rare and shall, therefore, be addressed in detail in Chapter 9 as a clean coal storage technique.

5.4.2 Closed Storage for Raw Coal

Storing raw coal in enclosed bins provides protection against the elements, minimizes the potential for airborne pollutants and provides for near 100% live storage. Various types of enclosed bins and silos are available. The majority of the larger capacity bins are cylindrical in shape and usually are made of steel or concrete.

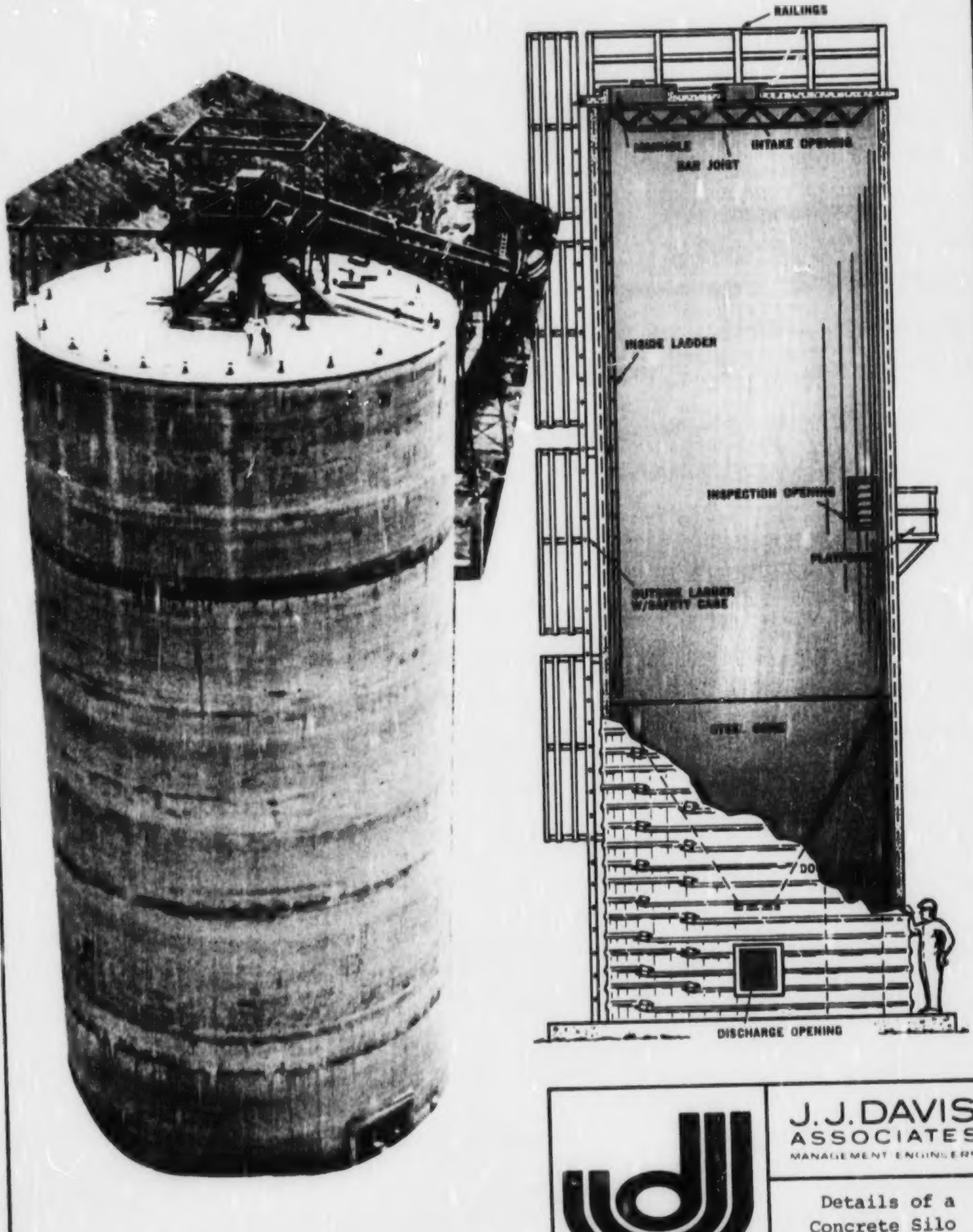
5.4.2.1 Steel Storage Bins The typical steel raw coal storage bins have between 1000 and 1500 ton capacities, although steel bins up to 60 feet in diameter holding approximately 4000 tons have been built and bins up to 100 feet in diameter with capacities of 10,000 tons have been proposed. Steel storage bins have sloping bottoms constructed of steel plate which makes possible the gravity withdrawal of all the raw coal contained within. In preparation facilities that clean coal for more than one company, the use of several of these steel storage bins allows for the segregation of the individual property. In other cases where the coal from varying sections within a mine or from various mines have significantly different characteristics, several steel storage bins may be required to assure proper blending of the coals to obtain a uniform feedstock for the plant.

Low capacity steel storage bins are less expensive to construct than similar concrete silos; however, their capacity per diameter (floor space consumed) and maintenance problems (especially when corrosive high-sulfur, high-moisture or highly abrasive coals are handled) minimize their use in new preparation facilities.

5.4.2.2 Concrete Silos--With the advent of new concrete construction technology and the increasing size of raw coal storage facilities (larger than 1500 tons), it is now more economical (when the costs are expressed in dollars per ton of storage capacity) to construct storage facilities of concrete. Additionally, when storage is expressed in terms of floor space utiliziation, the concrete silo is usually superior.

A 60 foot diameter steel bin typically has a capacity of about 4000 tons, while a 70 foot diameter concrete silo will have a capacity of up to 10,000 tons.

As with the steel bins, the concrete silos provide nearly 100% live storage of raw coal and excellent protection from the elements plus they eliminate all the pollution problems associated with coal storage. The details of a concrete silo are shown in Figure 5-13.



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Details of a
Concrete Silo

Figure 5-13 DCN

REFERENCES AND/OR ADDITIONAL READING

Bituminous Coal Research, Inc., "An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal", BCR Report L-339, September 1969, BCR Report L-362, February 1970, BCR Report L-404, April 1971, BCR Report L-464, April 1972

Charmbury, H.B., "Mineral Preparation Notebook", Pennsylvania State University

Coal Age, "Coal Preparation and Unit-Train Loading", July 1972

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Coal Age, "U.S. Steel Coal Preparation", Model Mining Issue, October 1973

Coal Research Bureau, "Underground Coal Mining Methods to Abate Water Pollution", West Virginia University, 1970

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Daub, Charles H., "The Oneida Plant", Mining Congress Journal, July 1974

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Deurbrouck, A.., "Survey of Sulfur Reduction in Appalachian Region Coals by Stage Crushing", U.S. Bureau of Mines Report of Investigations #8282

Felde, Stuart R., "Large Front-End Loaders in Western Coal", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Flygt Corporation, "Mine Dewatering Submersible Pumps", Brochure, 1975

Foreman, William E., "Impact of Higher Ecological Costs and Benefits on Surface Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jeffrey Mining Machine Co., "Jeffrey Mining Machine Company: Manufacturers Information", Columbus, Ohio

Jenkinson, D.C., "Some New Coal Preparation Developments in the United Kingdom", National Coal Board Bulletin M4-B148

Katen, Ken P.; Palowitch, Eugene R., "Shortwall vs Conventional Systems", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Kester, W.M., "Magnetic Demineralization of Pulverized Coal"

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

Korol, Dionizy, "Influence of Hydraulic Getting on Mechanical Coal Preparation", Przeglad Gorniczy, Year 12 #12, December 1956 (National Coal Board Translation Section)

Kuti, Joe, "Longwall vs. Shortwall Systems", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining,Metallurgical and Petroleum Engineers, Inc., 1968

Llewellyn, Robert L., "Coal Preparation", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York, 1968

Lotz, Charles W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Manwaring, L.G., "Coarse Coal Cleaning at Monterey No. 1 Preparation Plant", Mining Congress Journal, March 1972

McNally-Pittsburg Manufacturing Corporation, "Coal Cleaning Plant Prototype Plant Design Drawings", Department of Health, Education and Welfare Contract 22-68-59

McNally-Pittsburg Manufacturing Corporation, "Coal Preparation Manual #572", Extensive Analysis on McNally Pittsburg Coal Cleaning Technology

REFERENCES AND/OR ADDITIONAL READING
(Continued)

National Coal Board, "Hydraulic Transport of Coal at Woodend Colliery", September 1961

Nirtsiyev, "Hydraulic Extraction of Coal in the Donetz Basin Izdatel 'Stvo "NEDRA", Moscow 1969 (Translated by Terraspace)

Nunenkamp, David C., "Survey of Coal Preparation Techniques for Hydraulically Mined Coal", Published for Terraspace Inc., July 1976

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

Protopapas, Panayotis, "A Report in Mineral Processing", Department of Applied Earth Sciences, Stanford University, 1973

R.M. Wilson Company, Inc., "Mine Productivity Systems and Equipment", Catalog #288-P

Roberts & Schaefer Company, "Manufacturers Information Booklets", Chicago, Illinois

Roberts & Schaefer Company, "Design & Cost Analysis Study for Prototype Coal Cleaning Plant", August 1969

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant", January 1973

Stefanko, Robert; Ramani, R.V.; Chopra, Ish Kumar, "The Influence of Mining Techniques on Size Consist and Washability Characteristics of Coal", National Technical Information Service, Springfield, Virginia, August 1973

Tieman, John W., "Chemistry of Coal", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York 1968

Wemco Division, "Manufacturer's Catalog", Envirotech Corporation, Sacramento, California, 1974

6. RAW COAL SIZING

6.1 OVERVIEW

There are three general reasons for sizing operations in commercial coal preparation practices today. They are:

- to separate raw coal into various sizes to feed different types of cleaning units,
- to assist in the recovery of fines in the original feed and in the recovery of fines produced during the processing operations and
- to assist in the recovery of solids used to control the specific gravity in cleaning units.

The raw coal sizing module includes primary and secondary size separations with the resultant material being raw coal feed that is distributed to three separate processing circuits--coarse, intermediate and fine. This module is shown in Figure 6-1.

Most coal cleaning processes require that for maximum efficiency the coarse and fine sizes be cleaned separately. Raw coal is separated by size (sized) in a wet or a dry screening operation with the choice being dependent upon the method of additional processing. It must be noted, however, that screens are used many times during the coal cleaning process and that this section of the manual addresses only the initial sizing process. An example of the varying screen uses is given in the following scenario (numbers refer to details shown in Figure 6-2):

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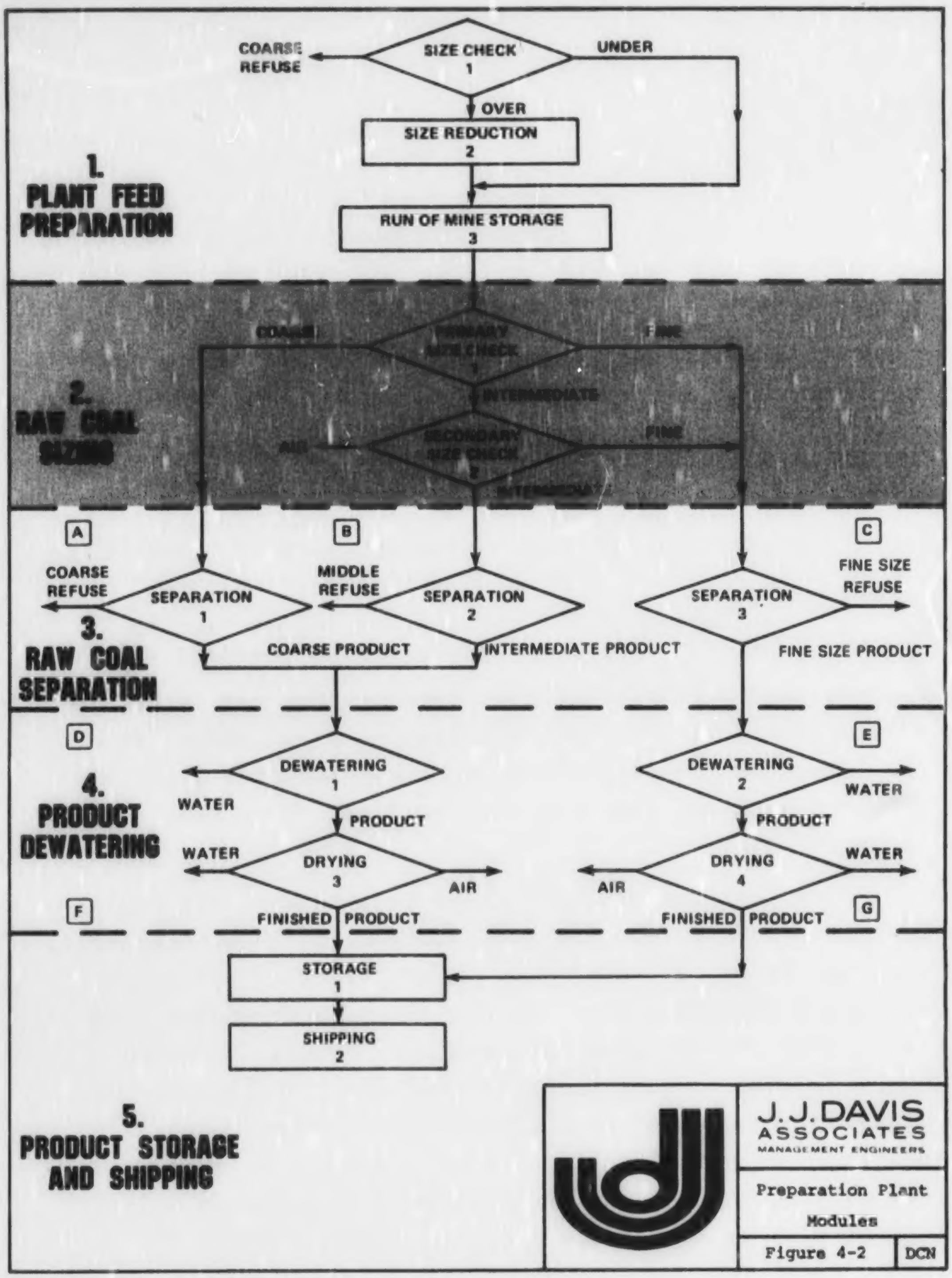

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Preparation Plant Modules

Figure 4-2 | DCN

The run-of-the-mine coal is fed to the scalping screen with the oversize from the scalper going to a crusher (1). Material going through the deck of the scalper is combined with the crusher discharge and fed to a raw coal sizing screen (2). The fine-size (slack) coal which goes through the raw coal sizing screen is either loaded out as a finished product or goes to module three for further processing (3). The material over the deck of the raw coal sizing screen is fed to a prewet screen prior to being fed to the coarse coal circuit (4). Float material from the coarse coal circuit is fed to a drain and rise screen which may be followed by a dewatering screen and additional sizing screens (5). The sink material from the coarse coal circuit is fed to a drain and rise screen with the refuse material being fed either to a dewatering screen or directly into a refuse bin (6).

6.2 NOTES ON SCREENING

The fundamental function of screening is to pass the undersized coal particles through the screen surface and to reject, i.e., pass over the screen surface, the oversized coal particles. The individual particles should be brought to the openings of the screen and presented to those openings at a minimum velocity and in such a manner that the passage of undersized particles will not be hindered or prevented by rebound from the edges or walls of the opening. If every particle of undersized coal could be brought to the screen openings individually, at substantially zero velocity, in a direction perpendicular to the plane of the opening, with the center of the particles projected cross section in line with the center of the last opening, and if the screening surface had no thickness, every undersized particle would pass through the screen. But tonnage requirements prohibit individual and low velocity presentation of coal particles, while mechanical considerations prevent perpendicular presentations of the particles to the openings and the use of very thin screening surfaces.

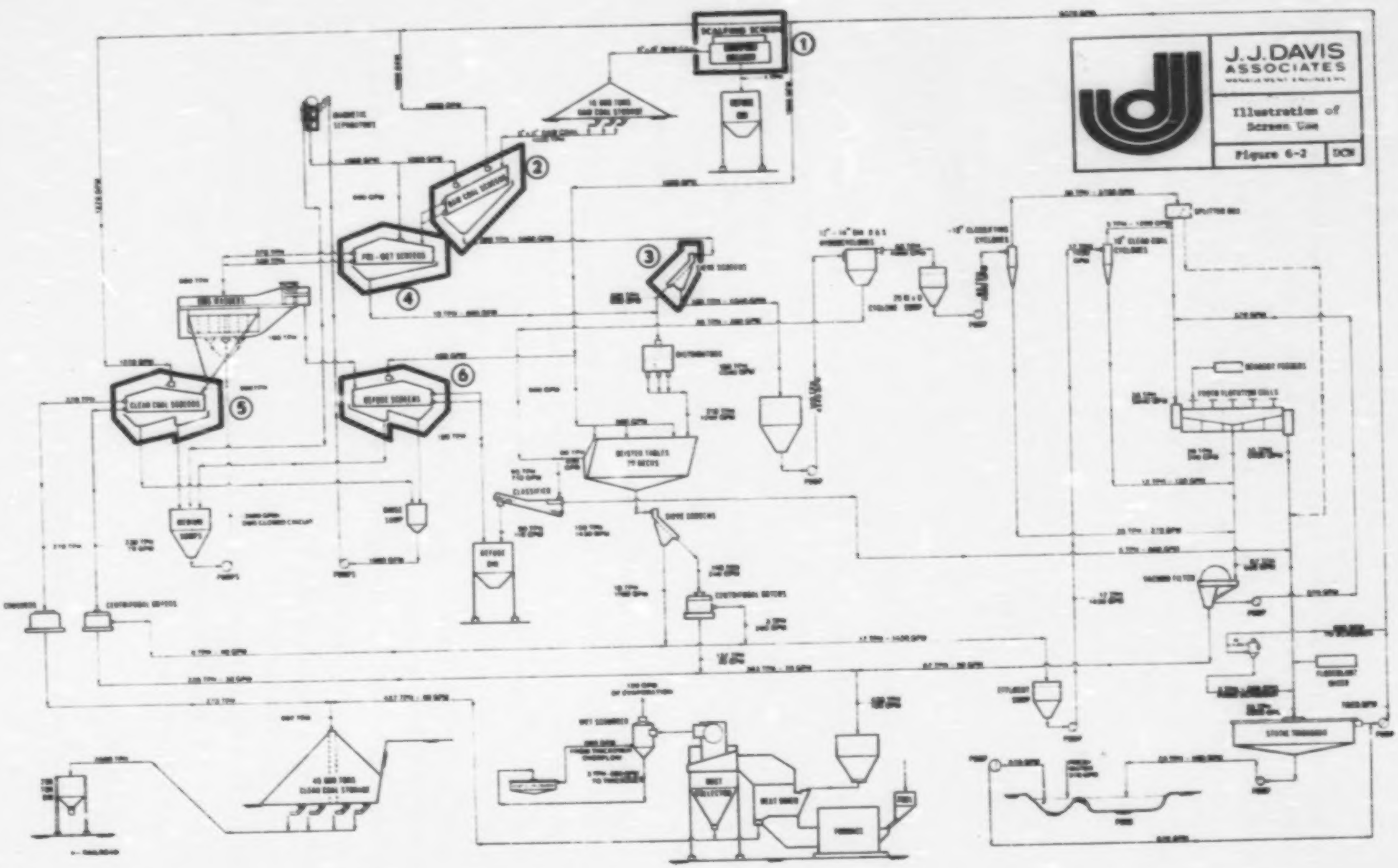

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Illustration of
Screen Use

Figure 6-2

In reality, then, the particles on the screening surface are crowded and continually interfering with each other at the openings; they are presented at high speed, nearly parallel to the screen surface with their most projected cross section in line with the center of the openings. As a direct result, many of the undersized particles are prevented for a considerable time from passing through the openings either due to their speed of travel or their angle of attack, and many, in fact, are rejected entirely as oversized.

Most of the screening principles in past practice have assumed that the only force operating on a coal particle on a screen was the vertical component of gravity. Although in modern screening practics the vertical component of gravity is the principle force involved, other forces are brought into play. This is accomplished by:

- sloping the screens so that the horizontal component of the particle's momentum becomes the principal force affecting the approach of the particle to the opening and
- by shaking or vibrating the entire screen or its screening medium in such a way as to contribute additional forces to the particles. These forces aid in the stratification of particles above the screen and influence the angle, velocity and direction of the particles approaching the openings. The forces also give additional energy for the passage of smaller-than-opening particles or for the rejection for a later trial at passage of near-size and larger particles.

Thus, screening is not only a single static process of particles dropping through an opening under the influence of gravity, but a dynamic one in which each particle is aided in reaching a favorable position over, and given enough force to go through, an opening, or to be rejected for another try with different orientation at another opening.

In commercial sizing or screening, two basic processes take place:

- stratification--the process or phenomenon whereby the larger sized particles of coal rise to the top of the bed being shaken or vibrated while the smaller sized particles sift through the voids and find their way to the bottom of the bed, and
- separation--the process of particles presenting themselves to the openings and being rejected if larger than the opening or passed through if smaller.

Stratification of particles helps screening by the vibration action which forces the finer sizes through the screen wire while the coarser sizes, rising to the top, add force to push the small pieces through the opening.

It should be noted that stratification is continually upset or nonexistent in a rotary type or trommel screen. This offers some insight for the recognized lesser efficiency of the rotary screen versus a vibrating screen. On the other hand, the relative gentleness of shaker screens effect little stratification and they are consequently fed very thin beds of coal which also accounts for their relative inefficiency, in the sense of the ability of equal screening areas of various types to remove the undersized coal from a given feed.

In the separation process it is important to recognize that coal particles are of an infinite number of sizes and shapes, and it is required that the near-sized particles have the opportunity to present themselves to the opening in many different positions to insure their passage. The ratio of feed to a given screen size directly affects this separation function. Note that for low tonnages (tph of feed) the efficiency actually increases with increased feed. This is due to the fact that a bed of oversize coal particles on top of the marginal sized coal particles prevents the marginal sized particles from bouncing excessively, thereby increasing their number of trials to pass through the openings. This axiom is true up to a point. After the optimum is reached, the efficiency rapidly drops off as the feed increases simply due to the fact that the screen is not large enough (length vs width vs bed depth) to allow for the proper stratification which would ensure the necessary separation.

Figure 6-3 illustrates the stratification and separation of the coal particles as they move across a screening surface.

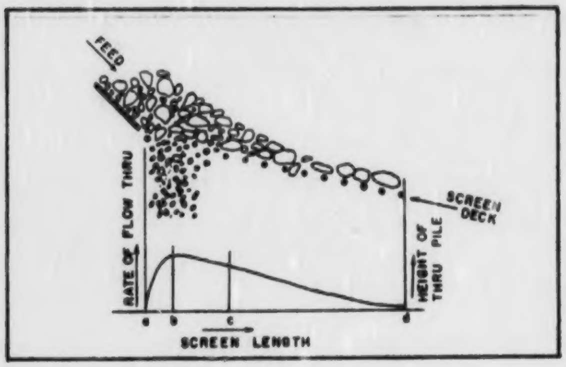


Figure 6-3

Representation of Screening
Action in the Longitudinal Direction

In Figure 6-3 the rise between "a" and "b" shows the effect of stratification taking place. The area "a" to "c" is often referred to as the area of saturation screening where particles up to about 75 percent of aperture size are crowding through the screen deck. In the area from "c" to "d" the final process of fit and pass or reject takes place.

The thickness of the coal bed on the screen deck is important to develop the ultimate screening efficiency. The speed of travel of the material on the screen deck determines the appropriate thickness. In addition, the slope or inclination of the screen affects not only the capacity in binding which is a term describing the lodging of pieces of coal or slate resulting in a decrease in open area for the particles to pass through the screen, but determines the rate of travel of the particles across the screen surface, which determines its thickness, etc.

Among the other factors affecting screening efficiency, the choice of the proper screening media is extremely important. In choosing the proper media, consideration must be given to the desired product size, the load on the screen and the metal that is most economical for the particular screening problems encountered.

The types of screening media now most widely used in coal preparation are:

- perforated or punched plate
- woven wire cloth and
- profile wire screens.

Perforated screens can be obtained in a variety of opening shapes and sizes in a variety of metals: Mild steel for normal applications, high carbon steel, A R steels and other trade alloys for extremely abrasive applications; and stainless steel and manganese bronze where corrosion is severe and where smaller openings are needed. Additionally, rubber, ceramic and synthetic coating on mild steel plates have proven successful on many extremely abrasive and corrosive applications. As Figure 6-4 illustrates, the perforations may be of various shapes and sizes. Additionally, the openings may be staggered to give the coal particles a better chance to find an opening through which they may pass.

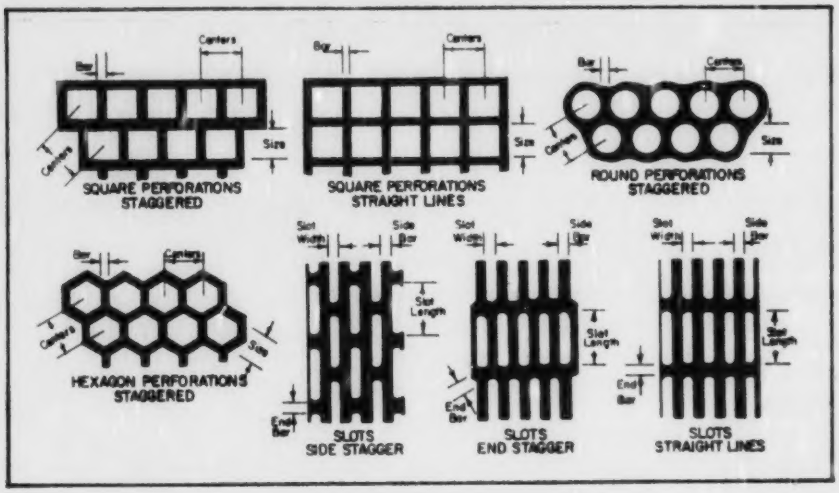


Figure 6-4

Standard Types of Perforated Screen

The percent of open screening area varies directly with the screening capacity and efficiency, but varies inversely with the load carrying capacity and the anticipated life of the screen. Woven wire cloth generally is used on vibrating screens where a maximum percent of open area is desired. The wire cloth in this application may be woven with wires of various diameters ranging from .02 inches to 1 inch. As with the perforated plate, special surfaces of rubber, enamel, etc., may be applied. In choosing the proper wire cloth, two factors are most important: sizing accuracy and screen life. The rectangular and slotted weaves provide more screening capacity than the square weave and are generally more efficient in screening coal, but less accurate in sizing. The woven wire cloth is available in all standard mesh openings and in space openings 1/8" to 10" (mesh denotes the number of openings per lineal inch and space denotes the actual dimension of the clear openings).

The final type of screening surface usually encountered on coal processing screens in the profile rod. The term profile is applied to this type of screening medium because the screen surface rods have a definite profile (cross section). The most common profile rods are shown in Figure 6-5.

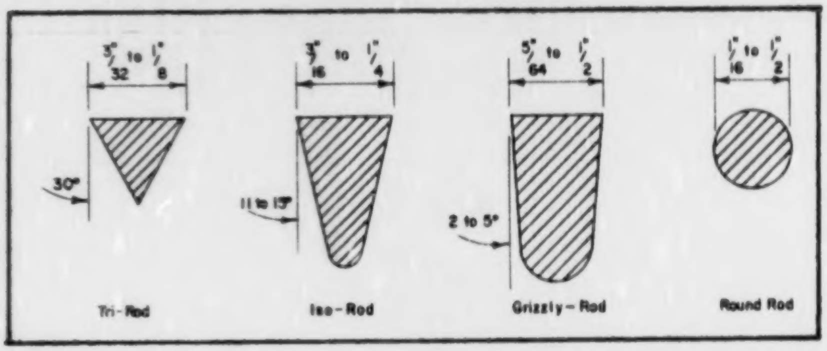
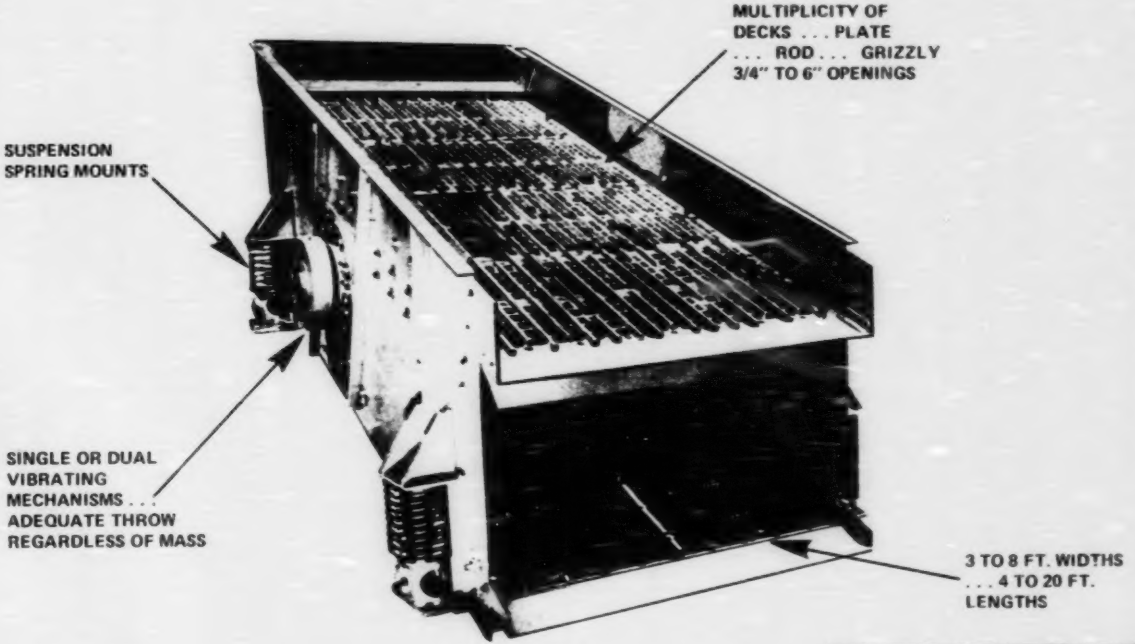


Figure 6-5
Common Types of Profile Rod Screens

Today, with the improved metal and design, there are many sloping vibrating units to choose from. The main problem is to establish the correct slope angle and screen area needed to accomplish the desired separation.

Vibrating screens (Figure 6-6) are the mainstay of today's coal preparation plants. They find application in all phases of coal processing--from scalping of raw coal to dewatering of extremely fine sizes of coal or refuse. The two types most commonly found in preparation plants



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TYPICAL DOUBLE
DECK INCLINED
VIBRATING SCREEN

Figure 6-6.

DCN

are the inclined, circle-throw, two bearing type and the horizontal, straightline stroke type. The choice of a particular type of vibrating screen, of course, depends upon which one has the characteristics that will best match the operating conditions and requirements.

Both horizontal and inclined vibrating screens are available in a wide range of sizes having single or multi-decks of whatever screening surfaces required. They may be provided with suspension mounts or base mounts. Base mounted screens are supported by four spring mounts which suspend the vibrating frame on stationary supports. Mechanically adjustable friction checks are provided at the spring mounts to serve as breaks to stabilize the movement of the vibrating frame and to prevent excessive, erratic movement in starting and stopping. Adjustable trunions and spring mounts permit adjustment by operating personnel of the top seat spring when changing the angle of inclination of the screen so that it is level and parallel to the bottom spring seat it supports.

The vibrating mechanisms consist of self-centered alloy steel shafts mounted in two high capacity, spherical rollers. The bearings and individual cartridge housings are attached to the side plates. The mechanisms are completely enclosed against the entrance of dust and to prevent the leakage of the lubricant. Gears are shaft mounted with tapered bearings. The oil seal assemblies are cartridge mounted in individual housings for easy maintenance. Single shaft drives are designed for straight-throw vibration; inclination and amplitude of the strokes are adjustable to suit the requirements of each application. The mechanism is V-belt drive and the driven sheave is a tapered bushing mounted to the shaft.

6.3 APPLICATION

6.3.1 The Raw Coal Screen

Raw coal separations are made at openings from 3/4" to 6 mesh with most of the separations occurring in the range of 3/16" to 5/16".

The raw coal screen is usually a single deck or double deck, two-bearing, circle-throw, inclined screen. The purpose of the top deck of the double deck unit is to relieve the load on the lower deck and to increase the overall capacity of the screen. Either wet or dry screening is utilized with the majority of the preparation plants being designed for wet screening. The duty of the raw coal screen is to remove fines--normally minus 3/16" in size--prior to the coarse coal sysle. The fines would upset the specific gravity of the bath if they were allowed to enter it, and they may be loaded out as slack coal or transferred to another part of the plant for further processing either in the intermediate coal circuit or in the fine coal circuit. (Refer to Figure 6-1.)

When dry screening raw coal, the surface moisture and the amount of clay present are important considerations and must be known. The major effect of these factors is the plugging of the screen surface with the secondary effect being the inefficient screening due to fine particles sticking to the coarse size particles, and riding over the screens with the oversized materials. The amount of moisture and clay which will produce binding is difficult to establish since it varies with the type of coal, the size of the feed and the screening surfaces used.

Vibrating screens for dry screening raw coal are selected by using standard screen selection formulae, except for the Pocohontas seam coals which are sized from a specific table. (These standard screen selection formulae may be found in The Screening Bible, publication PM 1.1 of the Allis-Chalmers Crushing and Screening Equipment Division.) Because of the variables in raw coal, it may be advisable to increase the calculated screen area by 20 percent to insure an acceptable installation.

Pocohontas seam coal is very friable and for this reason is much finer as it comes from the mine. This results in a greater amount of undersized particles to be removed and the screen areas calculated by the general formulae tend to be misleading. Screens handling Pocohontas coal are selected on the basis of the amount of coal passing through a square foot of the available screen area rather than on the total feed to a deck.

If only one separation is required of the raw coal screen and if the feed has a top size of about 4" to 7", a single deck screen can be used with wire cloth having the long dimension of screen openings parallel to the particle flow. This method has the advantage of using the larger sizes of coal to scour the cloth in order to prevent binding and allowing higher moisture coals to be screen dried. The disadvantages are the inaccurate sizing obtained with the rectangular opening and the increased wire cloth damage due to handling large feeds. The screening capacity of a single decked screen with rectangular openings in tons per square foot is high, but the single decked screens must be larger than double deck screens because the entire load is carried on one deck instead of being split to two decks. Manufacturer's tables give the recommended screening surface when dry screening raw coal on a single deck screen using rectangular openings with a maximum of 5 percent surface moisture in the screen feed. Other tables give the maximum surface moisture permissible in the feed when dry screening raw coal. If the moisture exceeds these amounts, binding or plugging will probably occur caused by the fine coal adhering to the screen wires or by wedge shaped particles lodging in the openings. Several methods to prevent binding may be used, including: increasing the amplitude or speed, changing the screening surface, using drag chains or by using a heated deck.

6.3.2 Pre-Wetting Screens

The raw coal may be screened either wet or dry depending upon the ultimate treatment of the fine fractions of the feed and the moisture content of the feed. If the feed preparation (raw coal screening) was performed dry, there may still be some fine coal particles adhering to the oversized coal. These must be removed so the fine coal will not interfere with the subsequent processing. If the surface moisture of the coal is high enough to make dry screening impractical, wet screening with sprays must be used. If the coarse coal is to be cleaned by the heavy media process, it is essential that the coal enter the vessel at a constant moisture content in order to maintain the specific gravity of the separating medium. Screens for wet sizing are selected by using the standard screen formulae. The pre-wet screening process is shown in Figure 6-7.

The amount of water used on pre-wetting screens depends upon the size of the coal and the amount of the undersized material to be removed. Three to six gallons per minute (GPM) of spray water per ton at a minimum of 30 psi is recommended for screening on wet screens. In addition, the feed should enter the screen in a soaked condition. This is usually accomplished by adding water

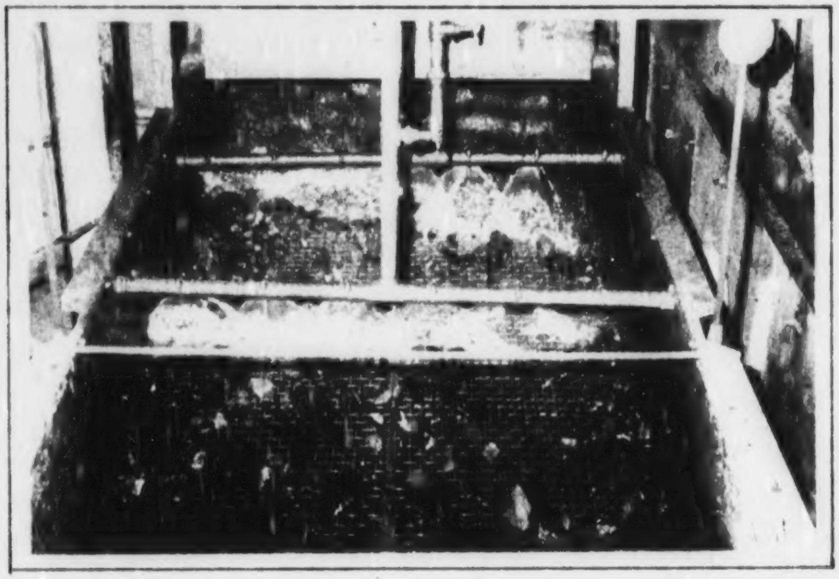


Figure 6-7

Pre-wet Screening Operation

to feed in the chute ahead of the screen. More water per ton of coal must be used on the finer separations and on double decked screens than on larger separations and on single decked screens. Usually two or more rows of sprays are used.

Capacity of pre-wetting screens is determined by the maximum depth of the material on the screen deck that can be successfully rinsed by water sprays. The maximum material depth will vary with the feed size since the smaller sizes are more difficult to rinse. Pre-wetting screens are usually selected so that the bed depth does not exceed two or three times the top size of the coal. Approximately 6 to 8 inches of coal is considered the maximum depth that can be pre-wetted completely.

REFERENCES AND/OR ADDITIONAL READING

Allis-Chalmers, "Screening Machinery", Engineering Bulletin on Selection of Vibrating Screens

Bituminous Coal Research, Inc., "An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal", BCR Report L-339, September 1969, BCR Report L-362, February 1970, BCR Report L-404, April 1971, BCR Report L-464, April 1972

Charmbury, H.B., "Mineral Preparation Notebook", Pennsylvania State University

Coal Age, "Coal Preparation and Unit-Train Loading", July 1972

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Coal Age, "Consol Preparation Confirms Coal Quality", October 1972

Coal Age, "Peabody Pioneers in Coal Handling & Preparation", Model Mining Issue, October 1971

Coal Age, "U.S. Steel Coal Preparation", Model Mining Issue, October 1973

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Daub, Charles H., "The Oneida Plant", Mining Congress Journal, July 1974

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Deurbrouck, A.W., "Survey of Sulfur Reduction in Appalachian Region Coals by Stage Crushing", U.S. Bureau of Mines Report of Investigations #8282

Kokunin, A.V.; Onika, D.G., "Hydraulic Underground Mining", Translated for Branch of Bituminous Coal Research, Division of Bituminous Coal, U.S. Bureau of Mines

Felde, Stuart R., "Large Front-End Loaders in Western Coal", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Flygt Corporation, "Mine Dewatering Submersible Pumps", Brochure, 1975

Foreman, William E., "Impact of Higher Ecological Costs and Benefits on Surface Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

Gospodarka, Gornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Humboldt-Wedag, "Manufacturers Brochures", Cologne, Germany

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiaiton of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jeffrey Mining Machine Co., "Jeffrey Mining Machine Company: Manufacturers Information", Columbus, Ohio

Jenkinson, D.C., "Some New Coal Preparation Developments in the United Kingdom", National Coal Board Bulletin M4-B148

Johnson Division, UOP Company, "Brochure - 1975"

Kester, W.M., "Magnetic Demineralization of Pulverized Coal"

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

Kollodiy, K.K.; Borodulin, V.A.; Nazarov, P.G., "Processing of Coal Mined by the Hydraulic Method", Ugol #9, 1974 (Translated by Terraspace)

Korol, Dionizy, "Influence of Hydraulic Getting on Mechanical Coal Preparation", Przeglad Gorniczy, Year 12 #12, December 1956 (National Coal Board Translation Section)

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Llewellyn, Robert L., "Coal Preparation", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York, 1968

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Lotz, Charles W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Lovell, Harold L., "Sulfur Reduction Technologies in Coals by Mechanical Beneficiation (3d Draft)", Commerce Technical Advisory Board Panel on SO_2 Control Technologies, March 1975

Manwaring, L.G., "Coarse Coal Cleaning at Monterey No. 1 Preparation Plant", Mining Congress Journal, March 1972

Mathur, S.P., "Hydraulic Mining of Coal", Journal of Mines, Metals and Fuels, May 1972

McNally-Pittsburg Manufacturing Corporation, "Coal Cleaning Plant Prototype Plant Design Drawings", Department of Health, Education and Welfare Contract 22-68-59

McNally-Pittsburg Manufacturing Corporation, "Coal Preparation Manual #572", Extensive Analysis on McNally Pittsburg Coal Cleaning Technology

Mengelers, J.; Absil, J.H., "Cleaning Coal to Zero in Heavy Medium Cyclones", Coal Mining and Processing, May 1976

Nirtsiyev, "Hydraulic Extraction of Coal in the Donetz Basin Izdatel 'Stvo "NEDRA", Moscow 1969 (Translated by Terraspace)

Nunenkamp, David C., "Survey of Coal Preparation Techniques for Hydraulically Mined Coal", Published for Terraspace Inc., July 1976

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

Protopapas, Panayotis, "A Report in Mineral Processing", Department of Applied Earth Sciences, Stanford University, 1973

Protsenko, I.A., "The Technology of Beneficiation andDewatering of Coal Mined by the Hydraulic Method", Questions Regarding the Hydraulic Production of Coal, Trudy VNIIGidrougol, Vol. XI, 1967 (Translated by Terraspace)

R.M. Wilson Comapny, Inc., "Mine Productivity Systems and Equipment", Catalog #288-P

Roberts & Schaefer Company Manufacturers Information Booklets", Chicago, Illinois

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Roberts & Schaefer Company, "Design & Cost Analysis Study for Prototype Coal Cleaning Plant", August 1969

Roberts & Schaefer Company, "Material Handling and Processing Facilities for the Mining Industry", 1974

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant", January 1973

Sal'nikov, V.R., "Experience and Outlook Regarding the Application of Hydromechanization of Steep Seams in the Kuzbass", UGOL #7, 1973

Schuhmann, Reinhardt, Jr., "Metallurgical Engineering, Vol. I, Engineering Principle", Addison-Westey Publishing Company, Inc., Reading, Massachusetts, 1952, p. 84

Sokaski, M; Sands, P.F.; Geer, M.R., "Use of a Sieve Bend and a Scalping Deck With a Vibrating Screen in Dewatering and Draining Dense Medium From Fine Coal", U.S. Bureau of Mines Report of Investigations #6311

Stefanko, Robert; Ramani, R.V.; Chopra, Ish Kumar, "The Influence of Mining Techniques on Size Consist and Washability Characteristics of Coal", National Technical Information Service, Springfield, Birginia, August 1973

Tieman, John W., "Chemistry of Coal", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York 1968

Tyler, C.E., "Testing Sieves & Their Uses", Combustion Engineering, Inc. Handbook #53, 1973 Edition

Wemco Division, "Manufacturer's Catalog", Envirotech Corporation, Sacramento, California, 1974

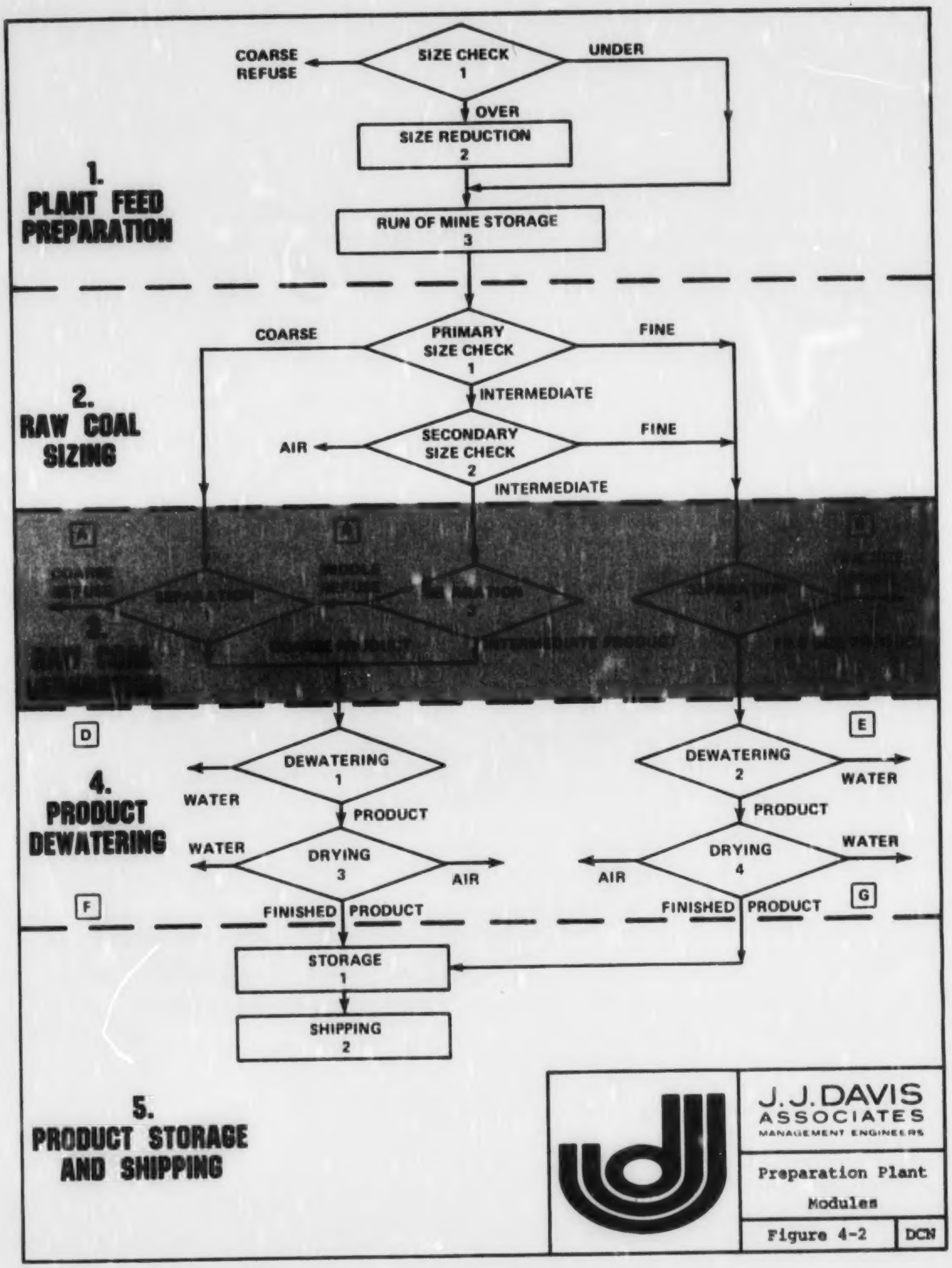
Yancey, J.F., "Determination of Shapes of Particles in Coal and Their Influence on Treatment of Coal by Tables", AIME Translation, 94

7. RAW COAL SEPARATION

7.1 OVERVIEW

The overall economics of a coal preparation plant are governed by a number of interdependent parameters which individually and collectively affect the final results. The most significant of these factors is the amount of salable clean coal, or plant yield. The plant yield is dependent upon the raw coal separation module. The raw coal separation module (module #5) highlighted in Figure 7-1 is defined as those portions of the preparation plant processes which either mechanically or hydraulically separate the coal from its associated impurities. Although by this definition moisture is considered an impurity, moisture will be specifically eliminated from discussion under module #3 and addressed in detail as a separate entity, "Module #4 Product Dewatering and Drying" in Chapter 8.

Once the theoretical yield for a particular coal has been determined from washability studies (see Chapter 11), the optimum return is achieved by approaching this theoretical yield as nearly as possible in a practical commercial operation. As indicated in Figure 7-1, raw coal separation is the largest process module and is extremely variable in regard to the number of possible combinations of equipment, the influence of the specific coals, the refuse/by-product generation, etc. Optimization, therefore, depends upon the combination of several



Preparation Plant Modules

Figure 4-2

processes to produce the ideal combination of the coarse and fine coal components which will result in the maximum yield of clean coal.

7.2 SPECIFIC GRAVITY SEPARATION

In the mechanical coal cleaning process, all of the commercially acceptable techniques to remove ash, sulfer and other impurities from the ROM coal are based upon specific gravity separation of the coal from its associated impurities with the exception of froth flotation (see 7.3.6). An understanding of the mechanism of specific gravity separation is essential to an understanding of the coal cleaning process. An ideal cleaning process is one in which all coal lighter than a pre-determined density is recovered in a washed product and all the heavier material is eliminated in the refuse. There is no mechanical coal cleaning process that can achieve this goal; however, some processes approach the goal more closely than others. The factors affecting the performance of these varying equipment configurations are discussed in the paragraphs which follow.

Coal usually of low specific gravity and the associated impurities of high specific gravity report largely to their proper product, washed coal and refuse respectively. However, as the specific gravity of separation is approached, the portions of misplaced material (that portion of material reporting to an improper product, coal in refuse or refuse in coal) increases rapidly. Figure 7-2 illustrates the impact of misplaced material as the specific gravity of separation is reached. The lower curve (B) is characteristic of the relatively sharp separation that can be achieved in dense-medium cleaning units (see 7.3 Methodologies). The upper curve (A) is characteristic of Baum jig cleaning units (see Section 7.3 Methodologies). With either type of cleaning unit, a high proportion of the near gravity material (the material just lighter or just heavier than the density of separation) reports to the wrong product.

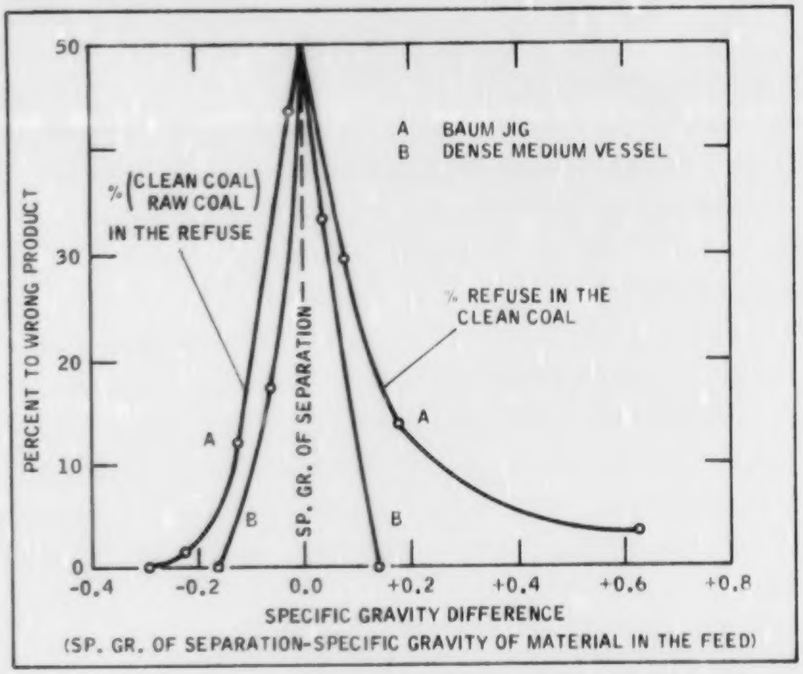


Figure 7-2

Misplaced Material in the Separation Products

The mechanics of the separation process is a complex physical process and one which to some extent has not been fully defined. Particle size and shape affect the degree of separation. The finer sizes of coal are treated less effectively than the coarser sizes in all cleaning processes. Figure 7-3 shows the unique distribution curves for a particular coal when both the coarse and fine

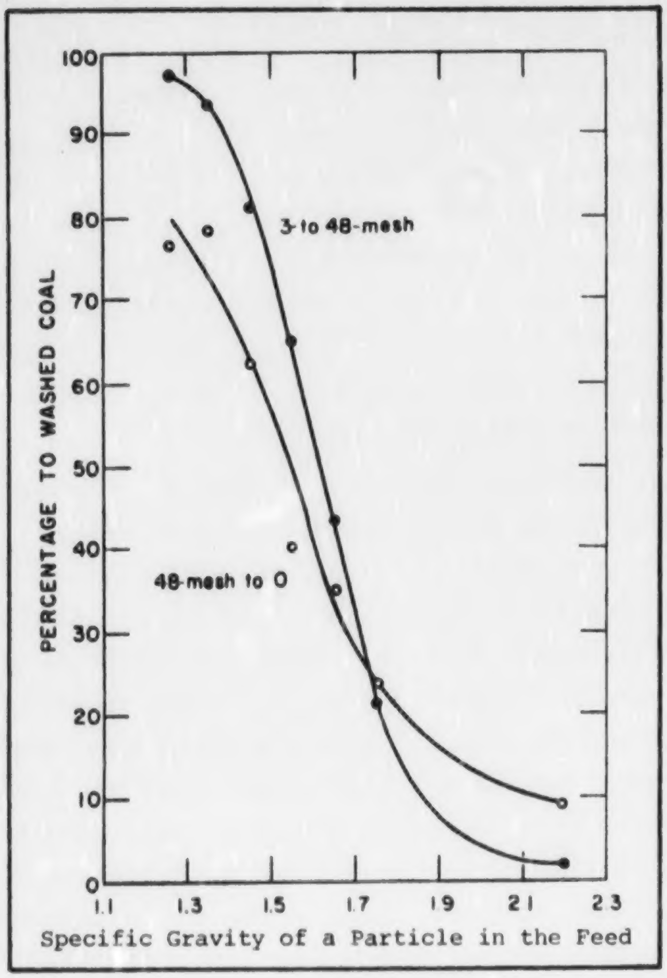


Figure 7-3

Distribution Curve of Raw Coal to Clean Coal
Coarse vs Fine Coal Fractions

fractions were treated on a table (see 7.3.5.3). The curve for the fine coal fraction, 48-mesh x 0, shows a considerably less sharp separation with a greater percentage of misplaced material. The presence of more coarse material in the fine coal feed may improve the characteristics of the curve. In the actual cleaning operation, certain types of washers require a rather small range in the size of the feed they will tolerate. Examples include the mechanical jig and most classifier-type units. However, even where the washer is designed to take all coal from 6" down to 0, some compromise must be made in the sharpness of separation. Consequently, if tonnage is fairly high and a sharp separation is desired throughout the full size range, several separate cleaning systems must be installed for the coarse and fine fractions, e.g., one system for 6" x 3/4", one system for 3/4" x 0" and one for the ultra-fines, 48-mesh x 0.

Research conducted by the U.S. Bureau of Mines indicates that the shape of the particles also affects the refuse sizes. The size and shape of a particle as well as its density determine its path in a moving fluid: flat, tabluar pieces are considerable more difficult to remove than are particles of more nearly cubic or spherical shape due primarily to the media's resistance to the particles which must pass through it, and to the fact that a mass of particles are being processed simultaneously which interferes with the free movement of particles within the medium. Other factors influencing the distribution curve include throughput, the mechanical condition of the cleaning unit, and the adequacy of the control of the cleaning unit and the feed rates.

The ideal condition for separation of coal with the heavier specific gravity refuse is a still bath of the proper specific gravity. The proper specific gravity may be achieved through true or artificial solutions, and the more precisely the specific gravity of the solution is controlled, the sharper the resulting separation. A number of systems have been developed to create the actual or artificial specific gravities needed to effect the separation which will be discussed in the next section.

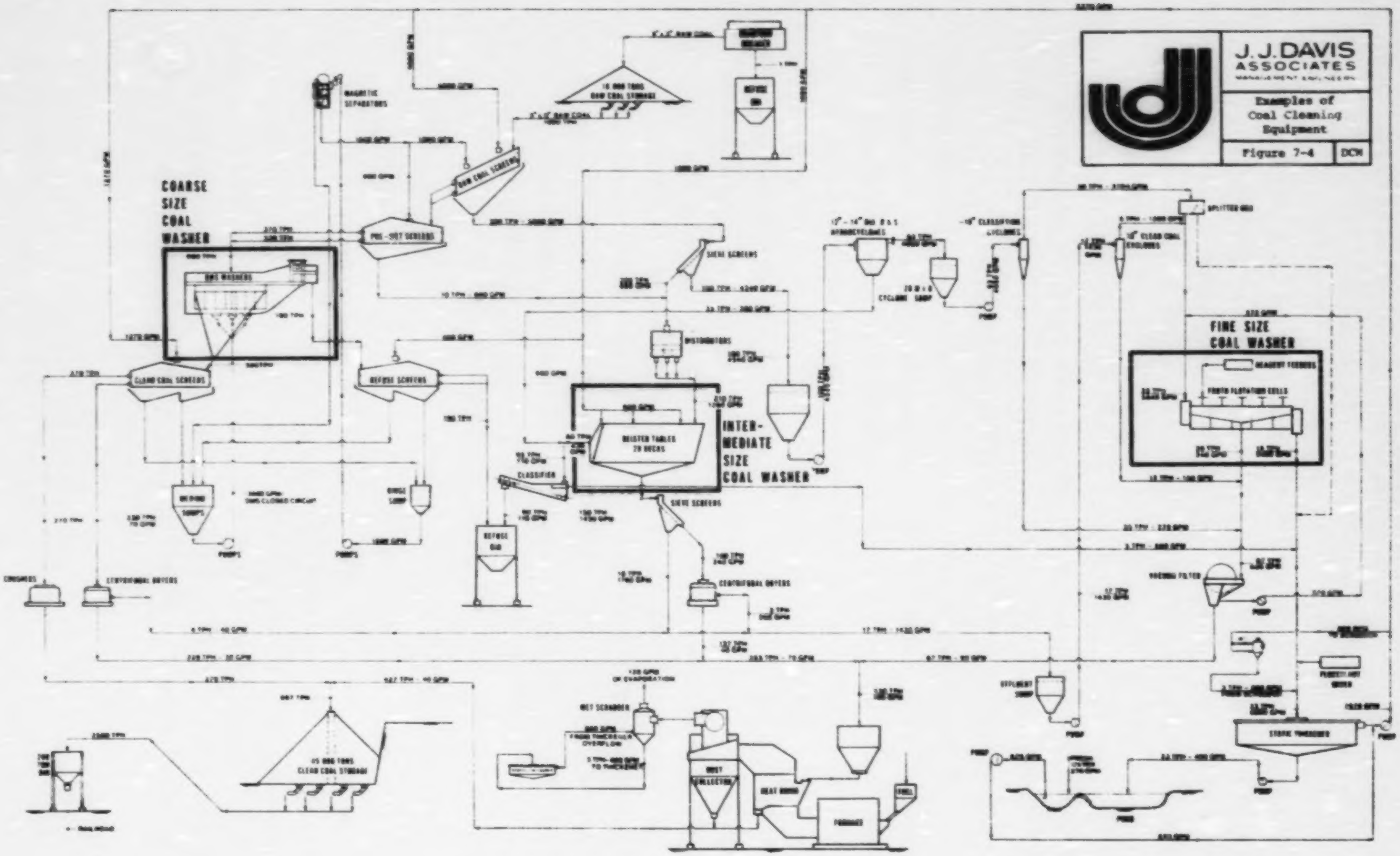
7.3 METHODOLOGIES

The methodologies of raw coal separation are varied and numerous. Figure 7-1 points out that the raw coal separation module has been broken down into three distinct process areas: coarse, intermediate and fine size coal cleaning circuits. One example of each of these areas is identified in Figure 7-4. For the purposes of this discussion, each of these categories will be addressed individually. It must be remembered that in reality there is considerable overlap among the systems.

The profitable operation of a coal preparation plant under today's stringent product standards and ever-rising labor and equipment costs requires that the preparation engineer continually strive for maximum recovery of salable coal. Reliable performance data are a prerequisite to the design of the new plant or to the expansion of existing facilities, and they serve as a yardstick with which the engineer can measure the performance of the plant. Having such data and a washability analysis of the raw coal, the preparation engineer can make a rational choice of cleaning equipment. Utilizing this data, the engineer may address each of the raw coal fractions (coarse, intermediate and fine) with the two main tools of coal preparation: Dense Medium Separation and Hydraulic Separation.

7.3.1 Dense Medium Separation of Coarse Coal

To meet the current product quality requirements, dense media vessels are cleaning an ever-increasing percentage of the total clean coal prepared. Today approximately 40% of the mechanically cleaned coal is washed through dense media equipment. Dense media cleaning is based on a rather simple principle. Just as small pieces of wood float while sand sinks in water, coal will



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Examples of
Coal Cleaning
Equipment

Figure 7-4 DCN

float while refuse sinks when placed in a medium that has a specific gravity which is between the specific gravities of the coal and refuse.

Commercial application of the dense medium process is a practical extension of the familiar laboratory float-and-sink test (see Chapter 11), which is used as a standard for 100% efficiency gravimetric separation. Commercial plants do not exactly duplicate laboratory float-and-sink separations for the following reasons: suspensions, rather than true liquids, usually are used as a separating medium; the introduction of feed and removal of the float-and-sink introduce disturbances in the separating medium; agitation, or upward currents in the vessel, normally is required to keep the separating medium in suspension; and the practical need for high throughput does not allow sufficient retention time for perfectly separating near-gravity material.

Theoretically, any size particle can be treated by dense medium processes; practically, however, sizes from 6" to ¼" are normally cleaned in the coarse coal circuit. The benefits of washing finer than ¼" material are usually offset by the increased medium loss and reduced cleaning capacity. The ideal separating medium would be a true liquid having the following properties: low in cost, miscible with water, capable of adjustment over a wide range of specific gravities, stable, non-toxic, non-corrosive and low in viscosity. Although no ideal medium exists, a variety of dense media have been developed, but only the suspensions of magnetite and sand have found widespread commercial application.

A suspension may be defined as any liquid in which insoluble solids are dispersed and kept in a state of fluid energy. The stability of suspensions used in coal preparation range from nearly stable suspensions using ultra-fine magnetite to highly unstable suspensions of relatively coarse sand in the Chance process.

The specific gravities of separation for coals range generally from about 1.35 to 1.90. To achieve this range of specific gravity while keeping the volumetric concentration at a reasonable level, it is necessary to either select high specific gravity solids or to introduce upward currents in the separating vessel. As the usually accepted volumetric concentration is between 25 and 45 percent, a size and specific gravity of the suspended solids must be selected that will provide for the desired separating specific gravity while at the same time have the required medium stability. The coarser the solids, the higher the settling rate, the lower the viscosity, and the easier it is to recover the medium; the finer the solids, the lower the settling rate (hence the greater stability), the higher the viscosity, and the more difficult it is to recover the medium. Additionally, the higher the specific gravity of the suspended solids, the lower the volumetric concentrations for a given specific gravity. It is, therefore, possible to select the specific gravity, size consist and volumetric concentration of the suspended solids to achieve medium characteristics that provide overall optimum performance and economy.

Control of density, viscosity and settling rate of a suspension is necessary for efficient separation of coal and impurities. A number of excellent discussions of these properties of a suspension are available (see references).

7.3.1.1 Magnetite Dense Media Coal Cleaning In general commercial usage, magnetite dense media coal cleaning is a separation of coal from the ash, pyrite and other impurities in a suspension of finely divided magnetite in water in which the coal floats and the impurities sink. The stability of the suspension of magnetite in the water is maintained by the fine magnetite grind, the amount of coal and shale slimes and the general agitation of the refuse-removal mechanism causing recirculation of the magnetite media.

There is no standard flowsheet for dense medium cleaning with a magnetite medium. Each plant is tailored to produce a specified product from a raw coal having specific washability characteristics. Functionally, the process involves the following operations:

- raw coal pretreatment,
- cleaning,
- product recovery and
- medium recovery.

- Raw coal pretreatment--Inasmuch as dense medium processes cannot process the full size range of the raw coal, it is necessary to limit the particle sizes of the raw coal fed to the washer. Limiting the top size of the coal sent to the washer is usually accomplished by crushing, screening or a combination of both and has been discussed in Chapter 6. The most important raw coal pretreatment function is the removal of those sizes too fine for washing by dense medium processes. If the finer sizes are to be marketed without further cleaning or if to be cleaned by dry methods, multideck vibrating screens using heated screen surfaces are used extensively. Where the fine sizes are to be cleaned wet, screening usually is accomplished on wet multideck vibrating screens or sieve bend screens. It is imperative that this function is done at high screen efficiency to prevent a buildup of fines in the medium circuit which increases the viscosity of the medium and significantly increases the loss of media.

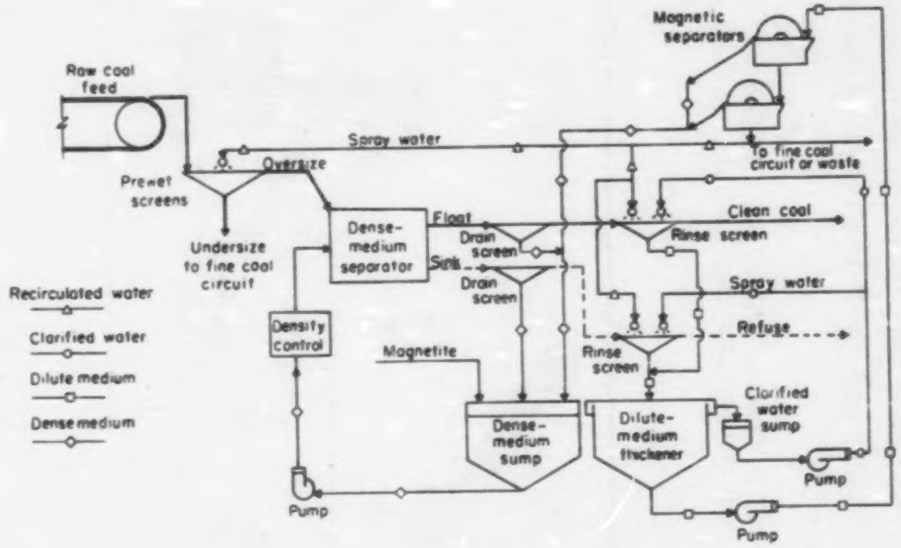
  In addition to presizing, the raw coal must be wetted before washing. This is accomplished automatically if wet sizing is used or can be accomplished by spraying the coal with water or dilute media, or by wetting in a sluice containing medium prior to its entering the washer. The surface moisture content of the raw coal entering the washer is usually between five and 10 percent depending on its size consist. One of the reasons for wetting the coal is to prevent "rafting" of particles in the separator; another reason is the need to feed to the separator a known and constant amount of water which can be compensated for by adding high specific gravity of the dense medium constant.

- Washing--The function of the washer is to effect a separation of the raw feed into a clean coal product and a refuse; some washers are designed to produce a middling product in addition to a clean coal product.

  Washers vary widely in design, performance, capacity and operation to the extent that there is a washer of the type and capacity available for any need. Because of the wide variety of washers, they will be covered later in the chapter.

- Product recovery--The products from the washer must be separated from the medium and the medium subsequently recovered. In most cases, the products flow over a short stationary screen where the bulk of the medium is removed without dilution and returned to the medium circulating system. The products then flow onto a vibrating draining screen for additional medium recovery and then onto a vibrating rinsing screen where sprays of water wash the remaining magnetite from the products. The screens are made sufficiently long to allow most of the water to drain from the products (see Chapter 8). The dilute medium from this operation is sent to the medium conditioning recovery system.

- Medium recovery system--It is the function of the medium recovery system to recover the magnetite that is rinsed from the products on the rinse screen and to remove the nonmagnetic material from a portion of the main medium circulation system for viscosity control. The amount of medium to be diverted from the main dense medium



Simplified, Typical Dense-Medium
Coarse Coal Washer Flowsheet

Source: U.S. Bureau of Mines
RI #7154

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Figure 7-5

DCN

circulating system rarely exceeds 10 percent. The actual amount that needs to be cleaned is a function of the amount of nonmagnetic fines that concentrate in the dense medium, due to either inefficient prescreening or the friability of the coal being washed.

The basic apparatus of a magnetite dense-medium coal washing process is illustrated in Figure 7-5. The system comsists of the following:

1. The separating vessel which is filled with the suspension of magnetite and water. Figure 7-6.

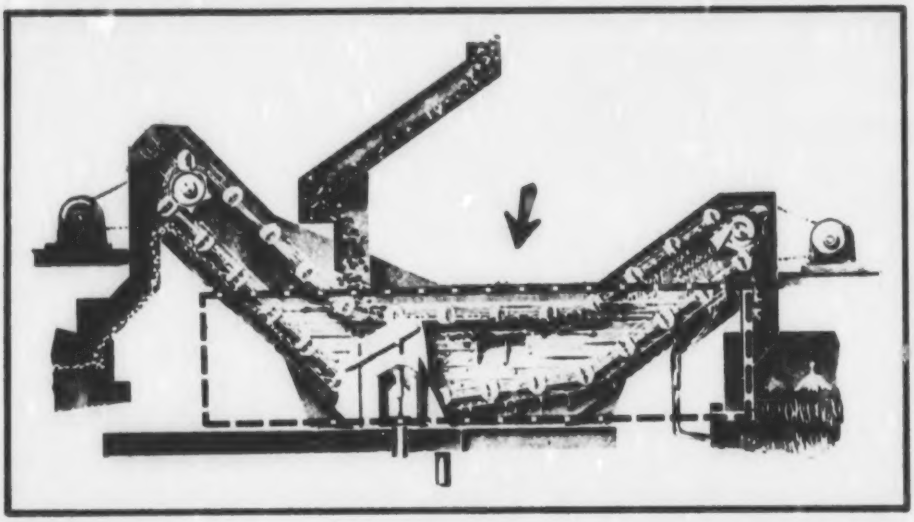


Figure 7-6
Dense Media Separating Vessel

2. An overflow weir or some means of mechanically assisting the coal across the surface of the bath and out the separator. Figure 7-7.

3. When a third product is desired, a middling removal system. Figure 7-8.

4. A refuse removal system. Figure 7-9.

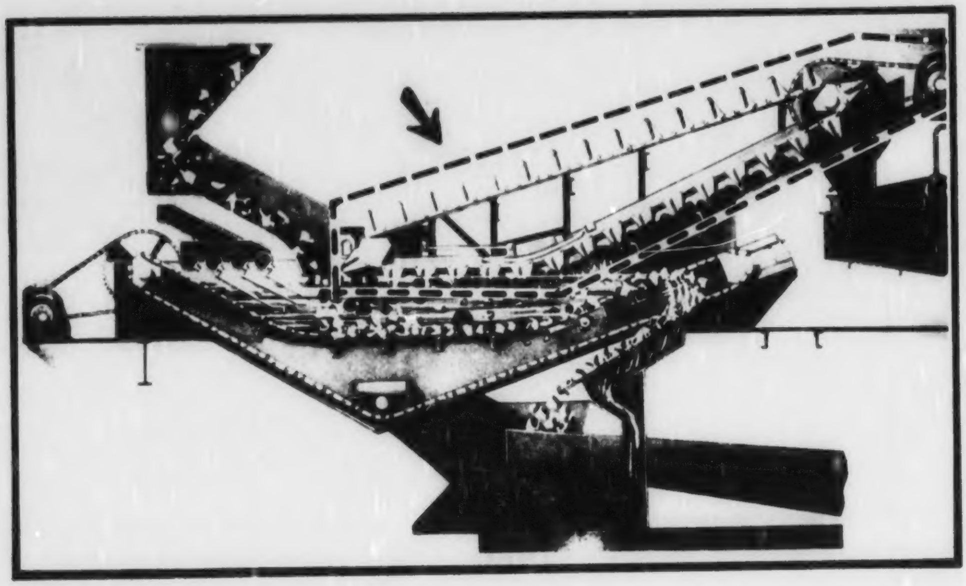


Figure 7-7

Mechanical Coal Removing System

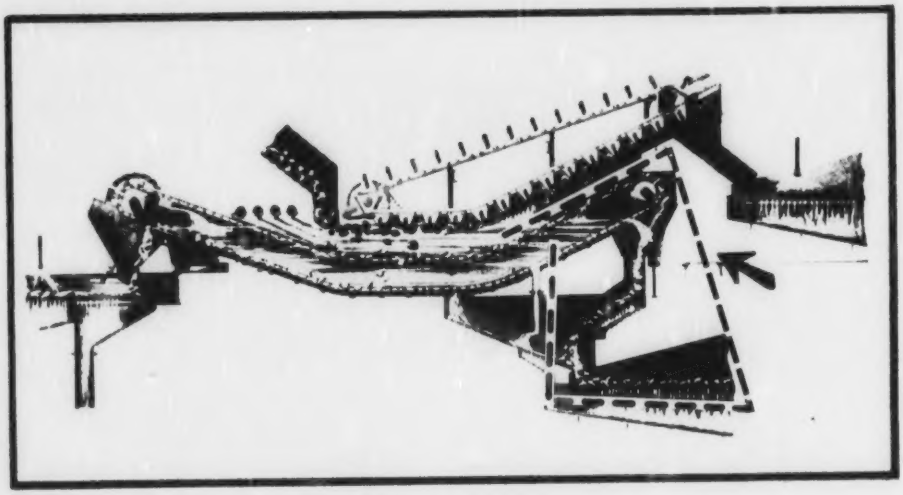


Figure 7-8

Middling Product Removal System

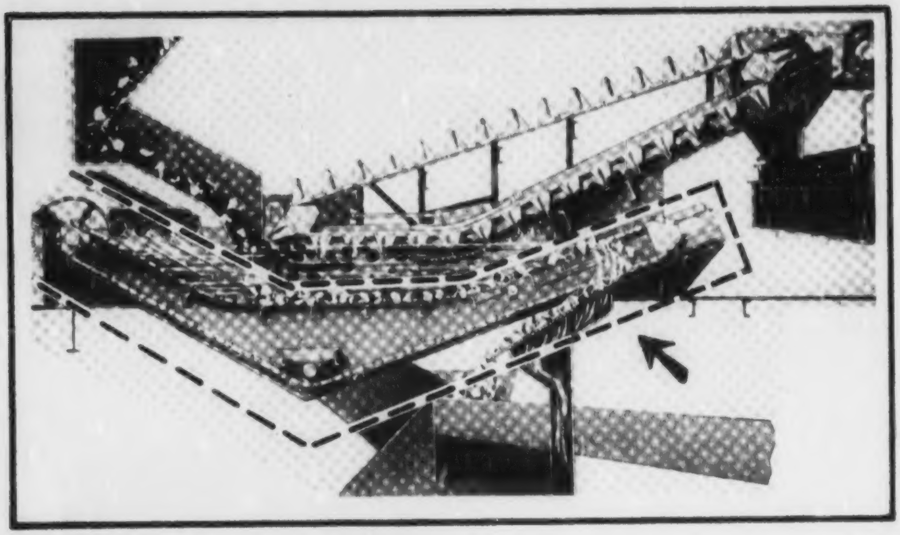


Figure 7-9
Refuse Removal System

5. Drain and rinse screens for removing magnetite media from clean coal, middlings and refuse products. Figure 7-10.

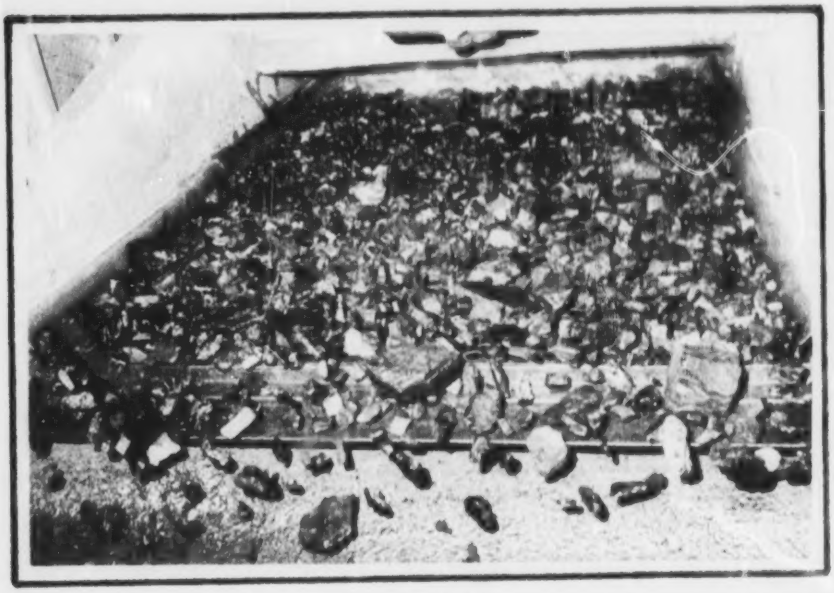


Figure 7-10
Drain and Rinse Screens

6. A dense media sump and pump which collects and drains media from all products and returns the media to the separating vessel. Figure 7-11.

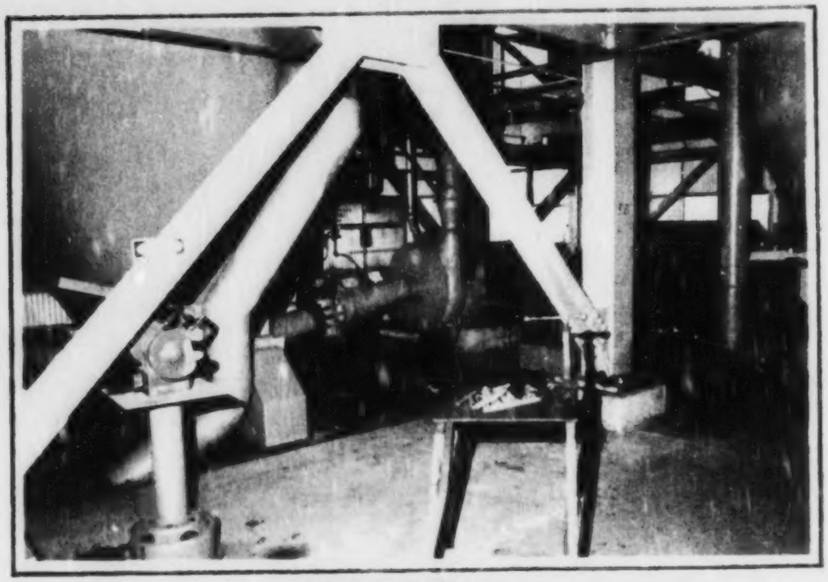


Figure 7-11

Dense and Dilute Media Sump and Pump

7. A dilute dense media sump and pump which collects the rinsings from the rinse screens of all products and sends a message to media recovery apparatus (see Figure 7-11).

8. A media recovery system is a cleaning system which densifies and cleans the magnetite from the associated coal and clay slimes. Figures 7-12 and 7-13.

9. A fresh water supply for rinsing sprays. Figure 7-14.

10. A magnetite feeding system which adds fresh magnetite. Figure 7-15.

11. A density control system which maintains a desired specific gravity in the bath. Figure 7-15.

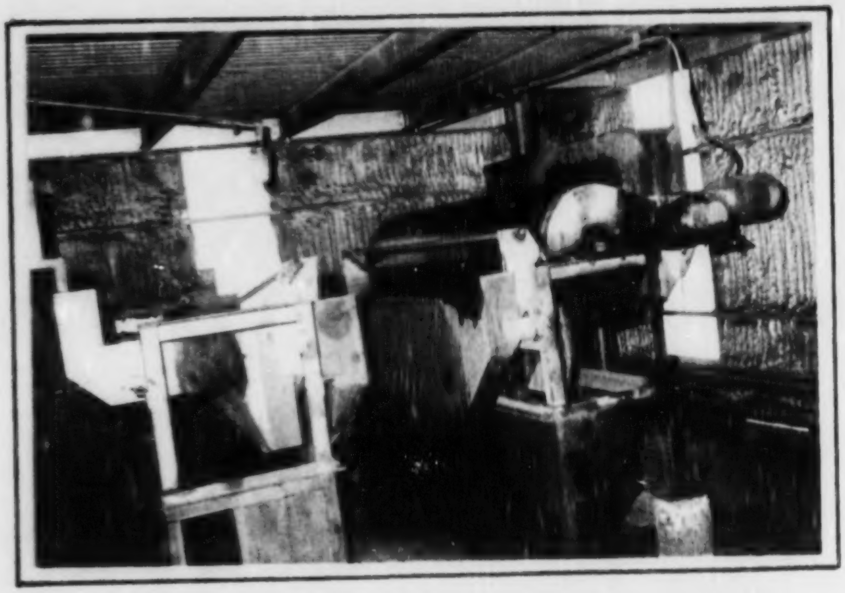


Figure 7-12
Magnetite Recovery Unit

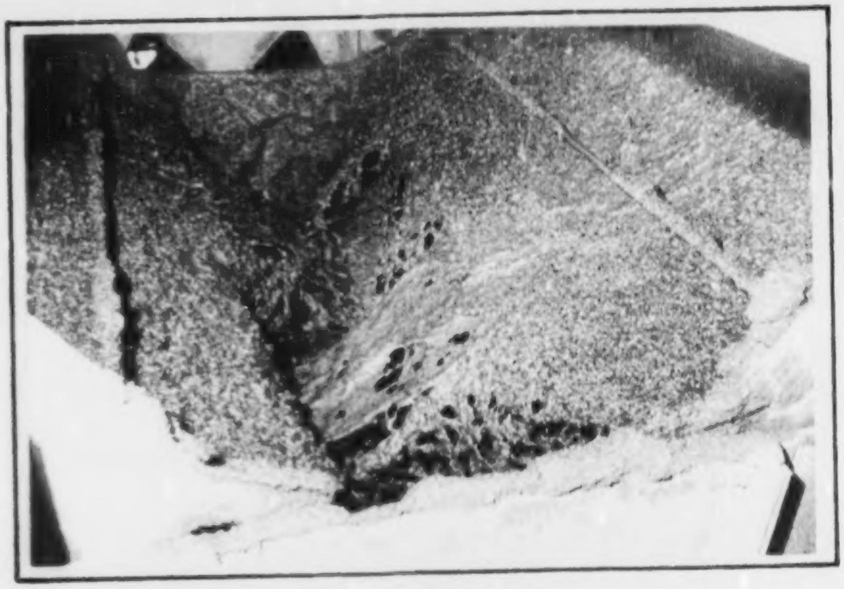


Figure 7-13
Recovery of Magnetite from Spent Media

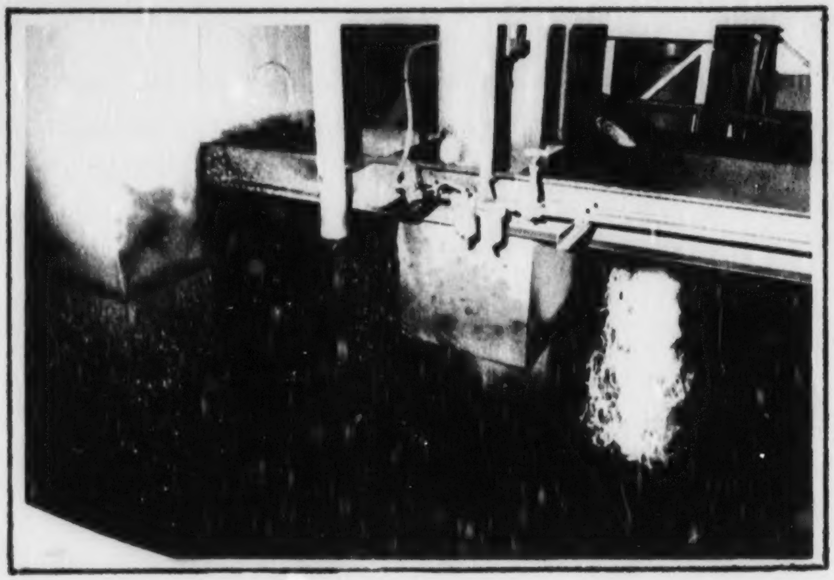


Figure 7-14
Make Up Water Head Tank

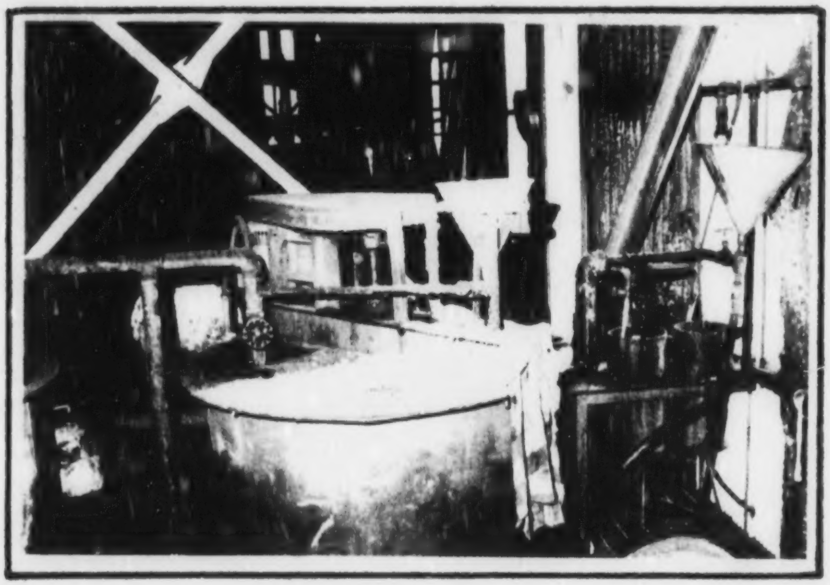


Figure 7-15
Magnetite Feed and Density Control System

The basic operational sequence begins as the sized feed for the vessel is pre-wet in a stream of circulating water and is introduced at or below the bath surface. The coal floats just below the bath surface and flows, or is mechanically assisted out of the separator with some of the magnetite medium. The high-ash material, shale and other impurities sink in the magnetite suspension and are removed from the bottom of the bath. The coal is drained, rinsed of media and sized. The refuse is drained and rinsed.

The drain portion from both products goes to the dense media sump for direct return to the separator to maintain the minimum level and stability in the bath. The diluted media from the rinsing portion of the product screens is piped to the dilute medium sump where the magnetite is thickened. The thickened magnetite is pumped to a double stage of magnetic separators for further magnetite concentration and medium cleansing. Overflow water from the diluted medium sump is returned to the surface as pre-wet and spray water. Figure 7-16 highlights a typical magnetite recovery circuit.

The concentrate (thickened) clean magnetite from the magnetic separator is returned to the separator bath via the dense medium sump. A portion of water and slimes removed from the coal and refuse by the magnetite separator may either be used in the pre-wet screen on the incoming feed, or may be sent directly to water clarifier-thickeners where the solids go to a fine coal recovery circuit and clarified water returns to the spray system.

The capacity of the separators (dense media washers) is a function of the size constancy of the feed, the quantity of near-separating gravity material in the feed and the amount of refuse in the feed. The width of the

Magnetite Recovery Circuit

The patented D.S.M. recovery circuit, used exclusively in this country by Roberts & Schaefer, is unique in its ability to keep magnetite losses to a minimum.

Each of the three main units of the recovery circuit has a specific function and, when combined in proper sequence, they produce the most efficient circuit for the recovery of magnetite.

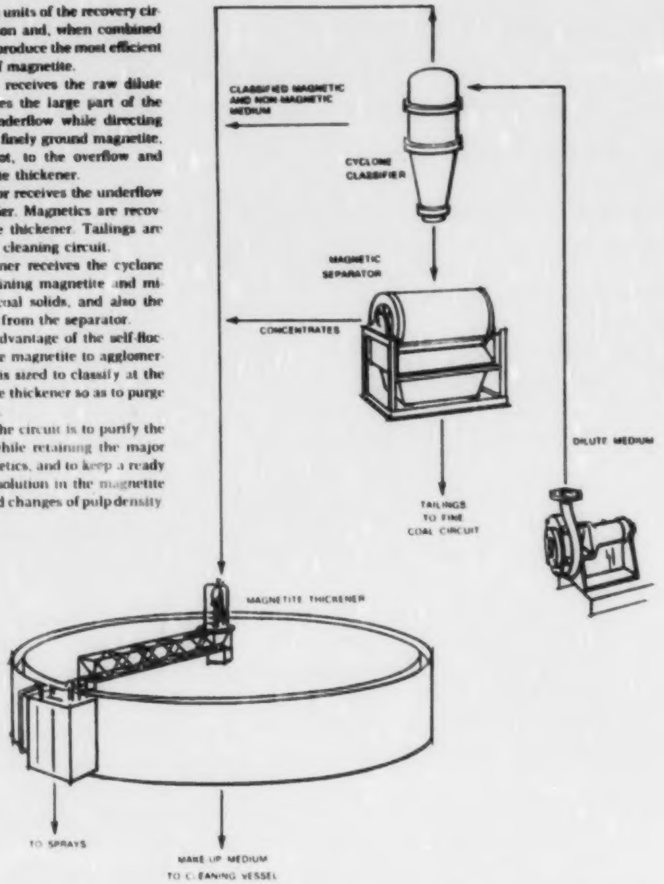
The cyclone classifier receives the raw dilute medium and concentrates the large part of the non-magnetics in the underflow while directing the major portion of the finely ground magnetite, whether magnetic or not, to the overflow and thence into the magnetite thickener.

The magnetic separator receives the underflow from the cyclone classifier. Magnetics are recovered and directed to the thickener. Tailings are diverted to the fine coal cleaning circuit.

The magnetite thickener receives the cyclone classifier overflow containing magnetite and minus 150M (nominally) coal solids, and also the concentrated magnetite from the separator.

The thickener takes advantage of the self-flocculating properties of the magnetite to agglomerate it magnetically and is sized to classify at the same point as the cyclone thickener so as to purge the system of coal solids.

The overall effect of the circuit is to purify the medium at each pass while retaining the major portion of the non-magnetics, and to keep a ready supply of magnetite in solution in the magnetite thickener for use in rapid changes of pulp density.


CLASSIFIED MAGNETIC AND NON-MAGNETIC MEDIUM
CYCLONE CLASSIFIER
MAGNETIC SEPARATOR
CONCENTRATES
DILUTE MEDIUM
TAILINGS TO FINE COAL CIRCUIT
MAGNETITE THICKENER
TO SPRAYS
MAKE UP MEDIUM TO CLEANING VESSEL

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Magnetite
Recovery Circuit

Figure 7-16 DCN

bath controls the capacity which ranges from 10 to 15 tons of coal per hour per foot of bath width in the 1" to 1½" size ranges, and from 15 to 25 tons per hour in a 2" to 3" size range.

The use of magnetite (5.0 specific gravity) permits practical suspension density ranging up to 2.0 specific gravity. The lower limits per semi-stable suspension is about 1.30 specific gravity.

The performance data of various sized fractions of all the plants studied by the U.S. Bureau of Mines support the following conclusions:

- The recovery efficiency is generally decreased as the size-fraction values decrease, but with little correlation to the amount of near-gravity material present.
- The separating specific gravity value increases as the size fraction value decreases, a normal characteristic of upward current vessels.
- The sharpness of separation criterion seems to substantiate the generally accepted theory that sharpness of separation deteriorates when washing finer material. This can be shown by the increase of probable error, the imperfection factor and the error area in the finest sizes.
- In general, the actual recovery, ash error and total misplaced material increase as the particle size decreases. The increase in total misplaced material is normally caused by an increase in the float coal reporting to the refuse.

7.3.1.2 Sand Cone Dense Media Coal Cleaning Sand cones are used to clean raw coarse coal with specific gravities below the practical range of Baum jigs, or to clean coals that are difficult to clean efficiently because of the amount of near-separating gravity material. present in the feed. Although sand cones normally clean +¼" coal, they are capable of washing +1/16" coal, but such use greatly reduces cone capacity.

Sand flotation, as applied to the washing of coal, means a floating of coal in a fluid mixture of sand and water in which bone, slate and other refuse will sink. A mixture of sand and water is maintained in a fluid state by mechanical agitation and upward currents of water having low velocity.

The most popular coal cleaning process using a sand suspension is the Chance Cone process, first patented in 1917. The first anthracite and bituminous coal Chance Cone plants were installed in 1921 and 1925, respectively.

The feature of the Chance Cone process distinguishing it from most other dense medium processes is that the sand particles are of such a size that they settle readily in water. The process, therefore, requires some method of maintaining the sand in suspension. This may be accomplished by stirring the sand-water mixture and using rising currents of water of such velocity as to hold the sand in suspension; the relative importance of each varies according to whether the specific gravity of the medium is high or low. In anthracite practice, where the specific gravity of separation is commonly 1.70 or higher, stirring is the primary method of keeping the sand and water uniformly distributed throughout the cone. In bituminous practice, where separations at 1.50 specific gravity are common, the rising currents are the primary method.

The Chance sand cone apparatus consists of the following:

1. a separator cone filled with a fluid mixture of sand and water,
2. an overflow weir to permit the coal to float out of the top of the separator,
3. a middlings column when a third product is desired,

4. a classifier column connecting with the base of the cone,

5. an upward refuse value,

6. a refuse chamber,

7. a lower refuse valve,

8. desanding screens for removing sand and water from the cone products,

9. a main sand sump to which all sand and water from the clean coal desanding screen is conveyed,

10. a refuse sand sump to which all sand and water from the refuse desanding screen is conveyed,

11. a circulating water pump to return water to the cone agitator nozzles and desanding sprays,

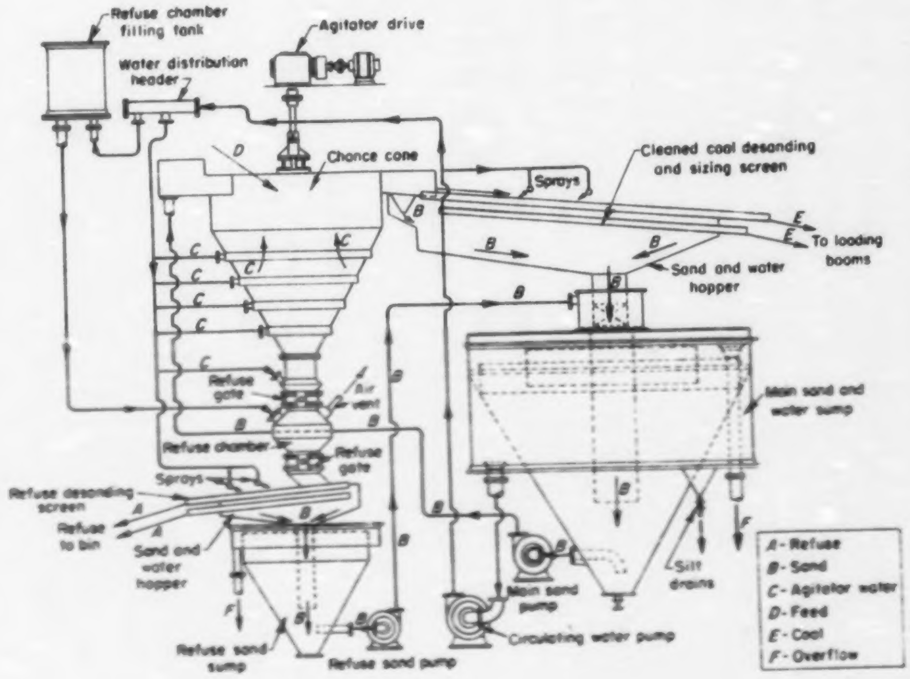
12. a refuse sand pump to return sand and water to the cone and

13. a manifold through which water for agitation is supplied to the cone.

Figure 7-17 depicts the Chance Cone process.

The basic operational sequence of the Sand Cone process begins with the feed to the cone being introduced at the vessel surface. The coal floats just below the surface of the fluid mass and flows out of the separator with some sand and water. The bone, slate and other refuse sink in the fluid mass and are removed by alternate opening and closing of the two refuse valves.

The coal is dewatered, desanded and sized simultaneously and the refuse material is dewatered and desanded. Sand and water removed by the desanding screens go to the sand sumps where the sand settles out. Sand from the refuse sump is pumped to the main sump and the sand from the main sump is recirculated to the cone. Overflow water from the main sand sump is returned to the cone and



Source: U.S. Bureau of Mines
RI #6606

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The Dense Media
Chance "Sand Cone"

Figure 7-17 DCN

desanding sprays by the circulating pump. Fine silt that settles out in the outer ring of the main sand sump is drained from the settling tank to a thickener for recovery of the water and the silt.

Owing to the upward water currents of low velocity in the sand cones, the large particles are floated at slightly lower specific gravities than the small particles. This characteristic of the cone may be either advantageous or disadvantageous depending upon the washability of the coal and the market.

Refuse removal is usually effected in a double-gated refuse chamber, which fills and empties from 20 to 60 times per hour depending on the quantity of refuse in the feed. However, one company successfully operates a cone that continually siphons the refuse product onto a desanding screen, thus eliminating the refuse chamber.

The feed particles to the separator may range from 8" to 1/8" in size, however, treating such a wide range would greatly impair the performance of the cone. When the size range to be cleaned is wide, it is preferable to size the feed and to use two separate washers. General practice in the United States is to feed 4" or 6" top size material with the bottom size of 3/8" or 1/4" to the separator. The benefits of washing coal finer than 1/4" in a sand cone probably are offset by the reduced capacity in increased sand losses. However, in certain instances coal is being washed down to 1/16" size successfully.

The capacity of the separator depends upon the size consist of the feed, the quantity of near-separating gravity material in the feed and the quantity of refuse in the feed. In general, this capacity is approximately two tons clean coal per hour per square foot of surface area.

Separator capacity may decrease if the feed is too closely sized or if the feed contains a large percentage of finer sized particles, excessive near-separating gravity material, or a large percentage of refuse. The nominal capacities of 10, 12 and 15 foot cones would be 155, 225 and 350 tons of clean coal per hour when washing 6" x 1/4" bituminous coal at 1.40 specific gravity.

The upper limit of practical separation specific gravity is approximately 1.65 using silica sand; the lower limit is about 1.35 specific gravity.

7.3.2 Dense Media Coarse Size Coal Washing Equipment

There are a number of commercially available dense media coal washing devices. Only a few of the more important units will be addressed to give the reader an idea of the range of equipment and techniques available.

The Tromp process, developed by K. Tromp in Holland, was the first to employ magnetite commercially as a medium. The distinctive feature of the Tromp vessel is a bath of dense medium which increases gradually in density from the surface downward. All other established processes aim at keeping the density as uniform as possible in order to make a sharp separation between the material which floats and the material which sinks. A common criticism of unstable media is that it is difficult to maintain the required uniform density. However, if the variation in density is controlled to a predetermined gradation as in the Tromp system, the advantage is gained that, in addition to the coal floating to the surface of the bath, the middlings and reject concentrate in the medium at different levels corresponding to their densities and, thus, the equivalent of series of float-and-sink separations takes place in one bath. This is achieved in the two-product bath by admitting controlled gravity recirculating medium of the same density through four feed points (headers) across the width of the bath. Directional baffles direct the medium to four zones vertically and horizontally. The gradation in medium settling is controlled by sending a medium to the bath which will give the correct specific gravity separation at the cut point where the clean coal scrapers leave the bath. The same purpose is achieved in the three-product bath for control of clean coal middlings separation. However, to control the refuse-middlings separation, medium of a predetermined higher gravity is admitted to the bath through a single point with its flow directed to the middle of the bath. The same gradation principle applies.

Three different Tromp vessels are marketed in the United States by the McNally Pittsburg Manufacturing Company and serve as the standards for shallow bath separators, two product separators and three-product separators.

- McNally Tromp Dense Media Vessel--The washing unit shown in Figure 7-18 consists of a shallow tank filled with a suspension of relatively coarse material. The medium is introduced by four horizontal pipes and distributed in horizontal layers across the feed end of the bath by baffle plates. It then travels the full length of the bath, the top layer flowing through the emission screen at the clean coal exit from the medium level and finally discharging with the refuse over the horizontal weir at the opposite end of the bath. The material to be separated is likewise distributed horizontally across the full width of the bath in a uniform layer. This is usually accomplished by means of a vibrating screen which serves as a double purpose of providing uniform distribution across the width of the bath and removing undersized material from the feed. The McNally Tromp bath makes a sharp separation by the use of the McNally Tromp principle of laminar flow combined with automatic density regulation. The laminar principle

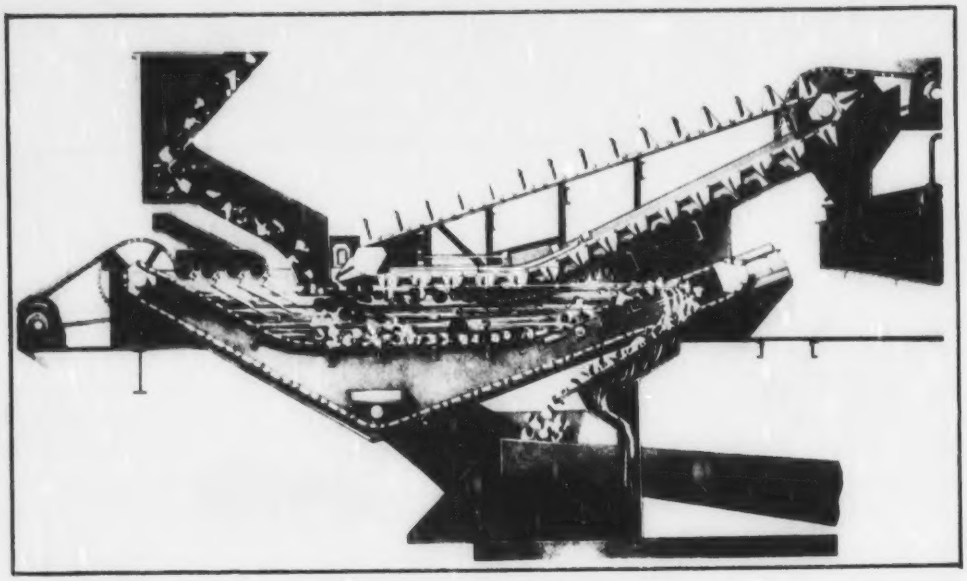


Figure 7-18
McNally Tromp Dense Media Vessel

provides for continuous, uninterrupted horizontal flow currents from the feed end to the discharge end of the bath. This action compensates for any tendencies of unstable media to settle out across the entire width of the vessel. By adjusting the fluid level the float material can be controlled to keep moving the full distance of the bath in a suspension layer of specific density. The automatic density control circuit consists of a density measuring device and a density recording controller to maintain the recirculating media at a constant, preset, specific gravity. A differential pressure cell is mounted on the side of the heavy media, recirculating sump to automatically control the level in the sump.

The bath is available in widths from 4 ft. to 10 ft. with capacities up to 475 tons per hour of raw feed depending upon the size range and the amount of sink material in the feed.

McNally Tromp Three-Product Dense Media Vessel--This vessel is designed to separate and clean three products from a raw coal feed. Therefore, a high and low gravity separation is obtained in a single unit rather than two. Figure 7-19 shows this unit.

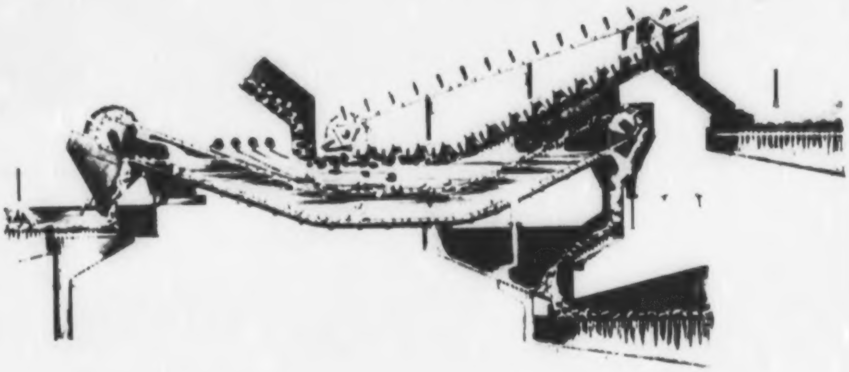


Figure 7-19

McNally Tromp Three-Product Vessel

Source: McNally-Pittsburg Manufacturing Company

McNally Tromp three-product vessel consists of a shallow tank filled with high and low gravity media consisting of a suspension of finely ground magnetite and water. A low gravity medium is introduced through the four horizontal feeders and is distributed in horizontal layers across the feed end of the bath by baffle plates. A high gravity medium is introduced into the lower portion of the vessel by a fifth header and flows in a horizontal layer escaping through the adjustable underflow gate.

The material to be separated is distributed horizontally across the full width of the vessel in a uniform layer. On entering the low gravity medium the coal floats and is removed by a scraper conveyor while the middlings and refuse sink to the high gravity section where the final separation of the middlings and refuse is made. The final separation is accomplished by a single scraper conveyor which carries the middlings float material on the top flight and the refuse sink material on the bottom flight.

The laminar principle functions as discussed. An air lift in the high gravity section accomplishes the same function for the high gravity media. There is a minimum of turbulence in the baths since the coal, media and conveyors move en masse in a substantially horizontal direction except for the refuse faction which settles vertically. The media density and level circuit is completely automatic.

- McNally Lo-Flo Dense Media Vessel--The Lo-Flo vessel shown in Figure 7-20 is essentially a tank filled with heavy media to which coarse coal is fed uniformly and gently. The operation of the vessel more closely simulates the actual laboratory sink-float conditions than any other production vessel in its capacity and operation.

  A single conveyor skims off the float product and on its return removes the sink product. The two products exit at opposite ends of the vessel. The density is controlled automatically either by bubble tubes, differential pressure (DP) cells, or nucleonic devices. Operating level in the vessel is maintained by constant overflow of the media.

  The Lo-Flo density media vessel is available in widths from 6 ft. to 9 ft. The capacity will vary with the size range and the amount of sink material in the raw coal feeds, changes or adjustments to the vessel which are required for varying feed characteristics may be quickly and easily accomplished.

Other types of dense media cleaning units are discussed in the paragraphs which follow.

- The DMS Dense Medium Precision Coal Washer, shown in Figure 7-21, is manufactured by the Daniels Company. It is a trough type unit using a transverse flow where the introduction of raw

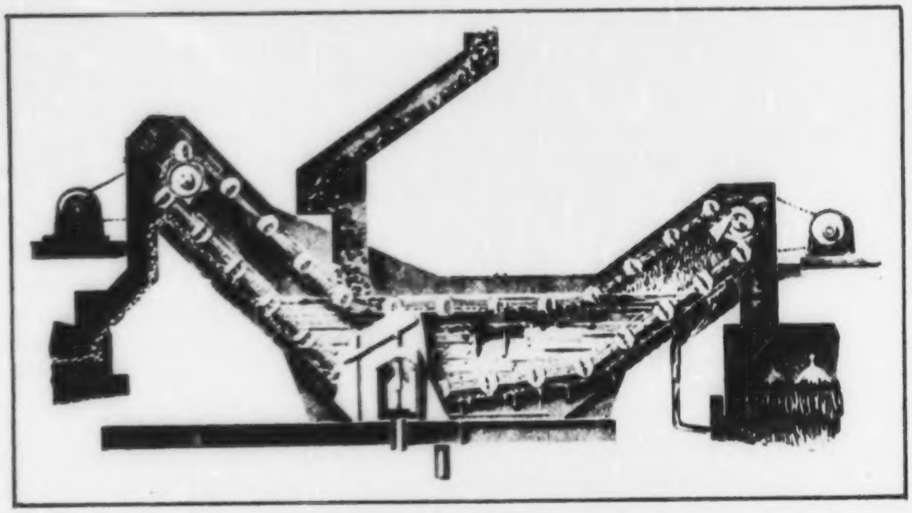


Figure 7-20

McNally Lo-Flo Vessel

Source: McNally-Pittsburg Manufacturing Company

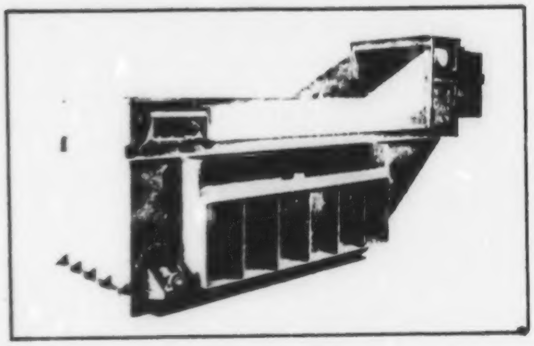


Figure 7-21

DMS Dense Media Coal Washer

Source: The Daniels Company

feed and the discharge of clean coal are transverse to the removal of refuse.

As the presized and prewetted feed enters the washer, it is forced under the surface of the bath by a patented submergence baffle. Thus, the actual separation between float-and-sink particles takes place well below the surface of the medium. Particles lighter than the specific gravity of the medium rise to the surface and overflow the weir along with a quantity of dense media; particles heavier than the specific gravity sink to the bottom of the bath where they are removed continuously by a slow-moving rectangluar flight conveyor.

Approximately 10 percent of the circulating dense medium enters the washer through a series of purge ports. This gentle upward current flows through the bedded refuse moving between the conveyor flights along the bottom of the vessel, purging the refuse of coal which might have become trapped.

The DMS Washer is available is capacities ranging from 100 tph to what is claimed to be the world's largest dense medium washbox, featuring a feed capacity of 800 tph, a refuse removal capacity of 250 tph and a clean coal overflow weir 20 ft. long.

- The Link-Belt tank-type heavy media separator (see Figure 7-22) is manufactured by the Link-Belt Company. Prewetted and sized feed enters the vessel together with dense medium of the desired specific gravity. The clean coal floats across the bath and discharges over a weir with the overflowing medium; the rejects sink to the bottom of the tank and are removed by means of a double strand chain-and-flight conveyor.

A greater part of the medium drained from the clean coal and reject is collected in a medium sump and is pumped back to the feed inlet sluice; the remaining medium is fed back to the funnel shaped bottom of the tank where it is used to create an upward current in the vessel to prevent the magnetite from settling.

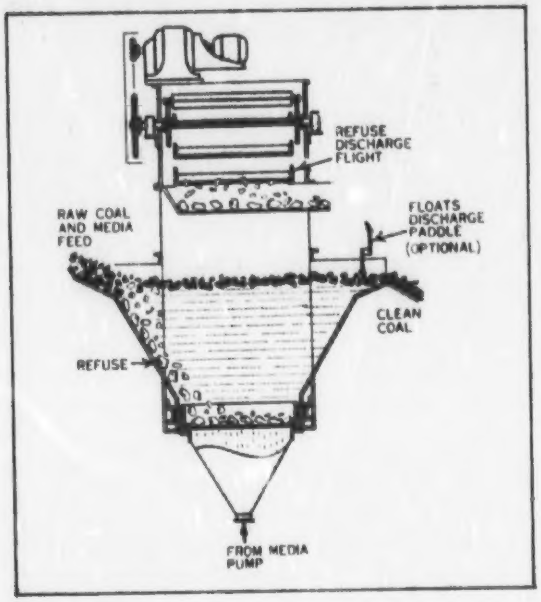
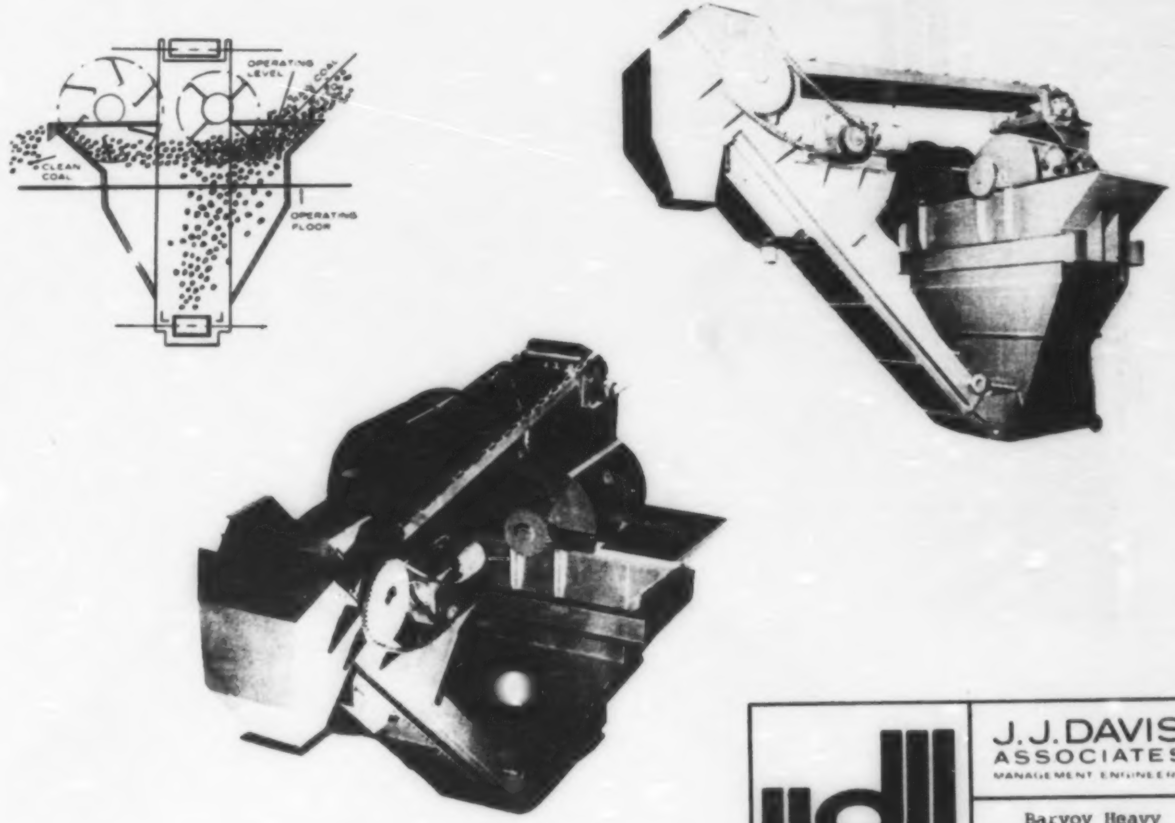


Figure 7-22
Link-Belt Tank-Type Heavy Media Coal Washer

- The Barvoys vessel, shown in Figure 7-23, is a deep trough-type vessel. The Barvoys System was designed originally in Germany for washing soft-structure coals and employed suspensions of barytes and clay which approached a true liquid. As now fabricated and marketed by the Roberts and Schaefer Company, it is designed to use a standard magnetite dense medium. The Barvoy trough-type washer utilizes lifters to remove the clean coal product out of the bath, thus reducing the quantity of medium to be recirculated through the unit. The refuse sinks to the bottom where it leaves the washer via a chain-and flight conveyor. Because of its down draft principle of operation, there is a minimum of degradation and no middling build-up or gravity fluctuation within this vessel. Capacities up to 500 tph per vessel are available.

- The DSM trough-type vessel, developed by the Dutch State Mines, is shown in Figure 7-24. It now is manufactured and distributed in the United States by the Roberts and Schaefer Company. The



Source: Roberts & Schaefer Company

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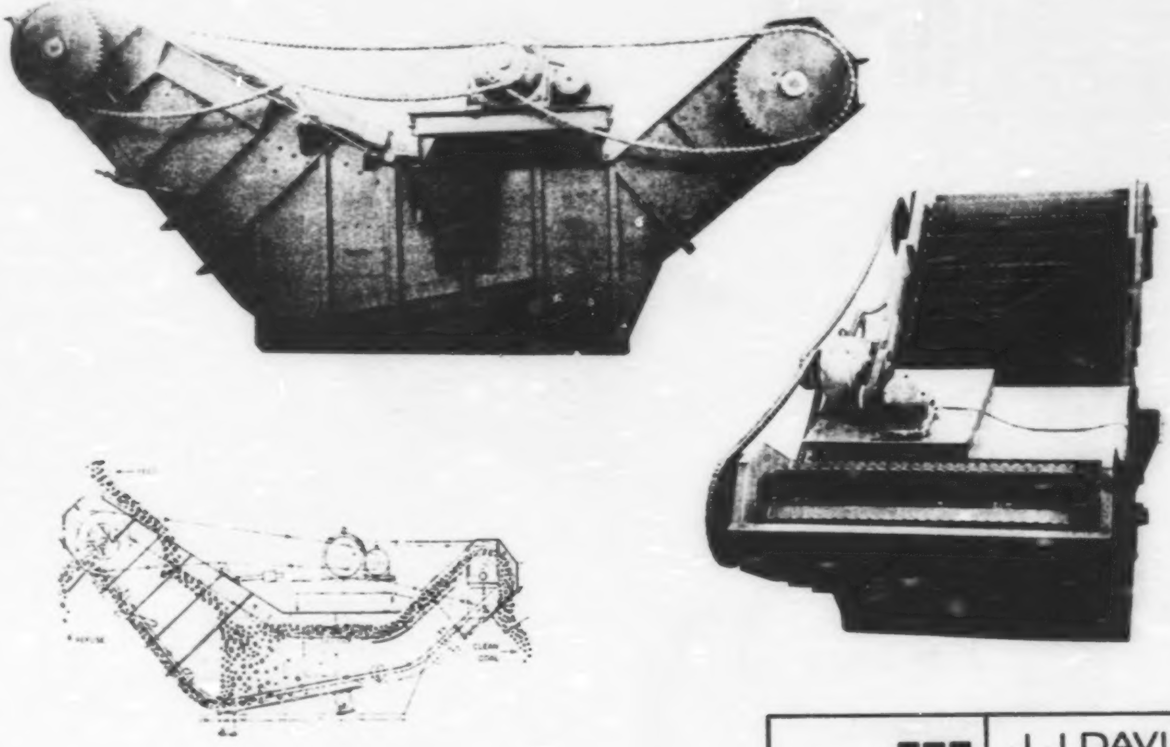
Barvoy Heavy
Media Vessel

Figure 7-23 DCN



Source: Roberts & Schaefer Company

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DSM Shallow

Bath Vessel

Figure 7-24 DCN

vessel uses a chain-and-flight conveyor for removal of the float-and-sink products. Vessels having a capacity up to 360 tph are available.

- Heyl and Patterson H&P Heavy Media Washbox for cleaning coarse coal is shown in Figure 7-25. Presized raw coal enters one side of the washer along with a small portion of dense medium. The float coal flows across the bath and overflows the clean coal weir with the bulk of the dense medium. Sink settles to the bottom of the vessel by means of a chain-and-flight conveyor.

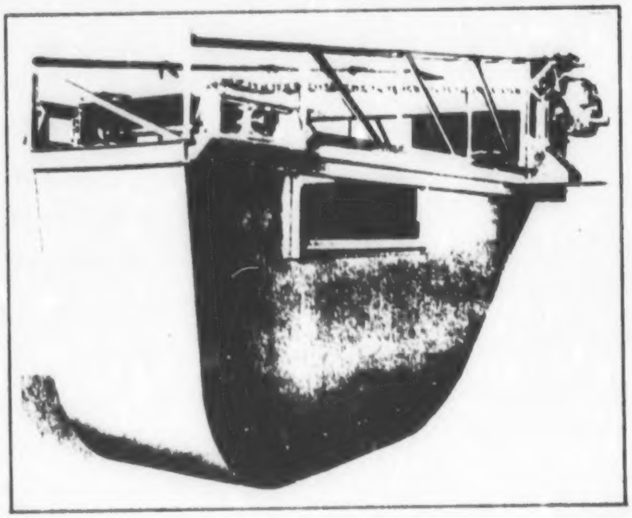


Figure 7-25
H&P Heavy Media Wash Box
Source: Heyl and Patterson, Incorporated

The major portion of the circulating dense medium enters the vessel via a baffle over the entire length of the feed side of the vessel where it discharges near the bottom of the bath. This flow of medium provides a gentle current which assists the float coal toward the clean coal overflow weir. A small portion of the dense medium is introduced at the bottom of the vessel to add stability to the suspension and to purge the sink of trapped float particles.

Dense media washers not specifically addressed include the miscellaneous manufacturers of the Sand Cone process and those that produce the different drum-type vessels, such as the WEMCO drum separator.

7.3.3 Hydraulic Separation of Coarse Coal

In general commercial usage, the hydraulic separation of coarse coal is restricted to jigging.

Jigging is a process of particle stratification in which the particle rearrangement is based upon the differences in their relative specific gravities and results from an alternate expansion and compaction of a bed of particles by a pulsating fluid flow. The particle rearrangement results in layers of particles which are arranged by increasing density from top to bottom of the bed. This response, developed from the many and continuously varying forces acting upon the particles, is a solid-fluid separation more related to particle density and less to particle size.

Jigging is one of the oldest techniques for washing coal. Jigs have been designed in many forms and they are still the most common type of coal cleaning device. Although some jigs have used only air as the separating medium, practically all jigs today use water as the medium. The water is actuated by means of pistons or air under pressure producing the pulsations required for the stratification of the lighter specific gravity coal particles from the heavier rock or impurities in the raw coal. One complete upward and downward movement of the water is called a cycle or revolution. A half cycle is called a stroke. The relative upward movement of the water through the screen is called the pulsion stroke; the relative downward movement of the water through the screen is called the suction stroke.

The stratification is usually carried out in a rectangular, open-top container, called a jig, in which the mass of particles (termed a "bed") is supported on a perforated base through which the water flows in alternating directions. Following the particle stratification, the particle bed is physically "cut" at any desired particle density plane thus creating the desired quality products. Figure 7-26 graphically simulates the results of the stratification process and highlights the susceptibility of the particle bed to physical cutting at desired particle density planes.

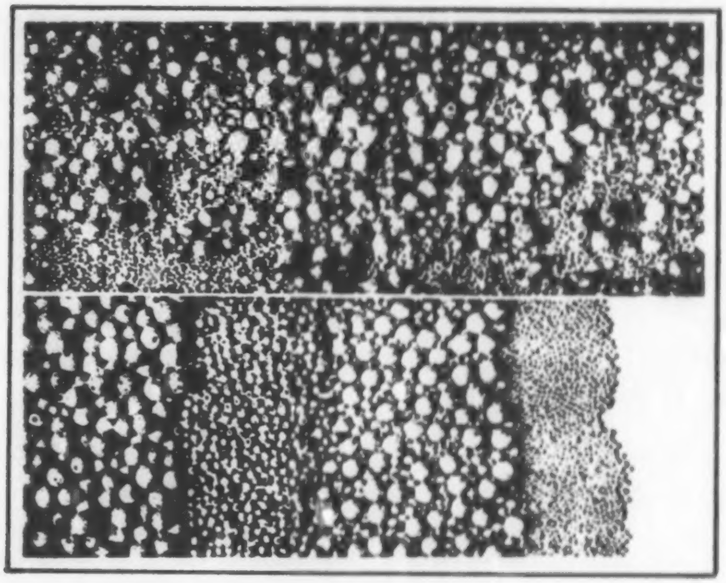


Figure 7-26
Simulated Results of Stratification Process in
a Coal Washing Jig

The mechanics of the jig includes the means for continuously introducing the raw coal for moving the water through the coal bed in a controlled manner as well as for separating and removing the stratified particles from the system in two or more product groups.

In coal preparation, this highly versatile unit operation is more preferably applied to a wide size-range of particles with top sizes up to eight inches than to a closely-sized fraction. Single jig washers have capacities from five to greater than 700 tons per hour of feed coal. The separation results attainable by jigging have favored this unit operation as optimum for creating a clean coal product as required by steam coal specifications. Although the jig is used in preparing coals which are difficult to separate, its limitations to achieve both quality products and high recovery are being recognized in comparison with heavy media-based processes which make sharper separations from feeds having high "near-gravity" contents. The accuracy of the densimetric stratification in the upper portions of the jig bed are less precise and, as in most mineral preparation unit operations, high recovery and product quality are interdependent and inverse process characteristics.

Jigs are made in three different types differing mainly in the mechanism for getting the reciprocating movement of the water relative to the screen:

- Plunger Type--in which the movement is caused by the reciprocating of a plunger moving in a compartment of the tank.
- Basket Type--in which the box containing the bed is reciprocated in still water.
- Air Pulsated Type--in which the tank is built in a shape of a U tube and the movement of the water is caused by applying low pressure compressed air to the closed leg of this U tube and then exhausting it.

The greater number (about 75%) of jigs in use are air pulsated and are called Baum jigs, named after the original inventor, Herr Fritz Baum of Germany, who developed it over 75 years ago. In America the Baum jig is built as a multi-cell series arrangement and since it takes a mixed sized feed and requires a source of compressed air in addition to the customary jig accessories, it does not lend itself to the construction of small units. Consequently, Baum jigs are the largest of this class of equipment.

The jig box is a U-shaped steel container divided into several sections as indicated in Figure 7-27. On one side, longitudinally near the top, is a perforated screen plate which supports the particle bed and on which the particle separation is effected. The region below the support screen and forming the bottom of the U is referred to as the "hutch compartment". Usually a screw conveyor is located at the

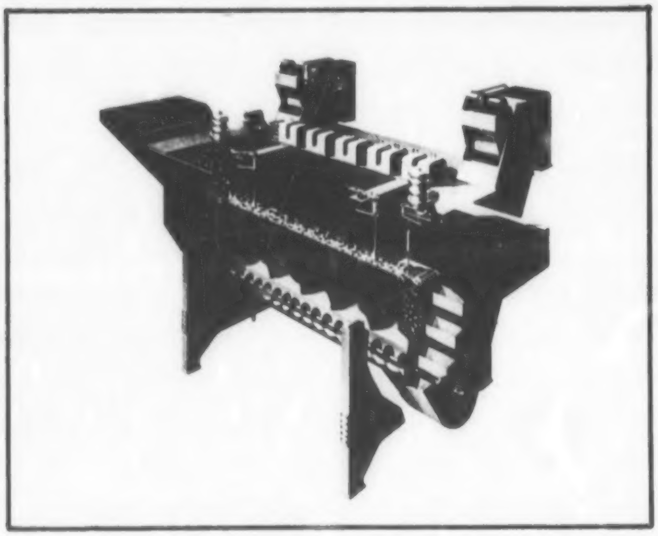


Figure 7-27
Typical Baum-Type Jig

bottom to remove fine particles which have passed through the screen with the flowing water.

On the side opposite the screen plate is a chamber (sometimes referred to as the pulsion chamber) in which the water pulsations are initiated. In the Baum jig, a sealed air chamber above the hutch water compartment is fitted with an air valve which connects to a high pressure air supply. This valve is actuated mechanically to admit air over the hutch compartment forcing water through the supporting screen base to expand the bed. In another valve position, the air above the water in the hutch compartment is allowed to exhaust under the pressure head developed by the water and particles. In the plunger or "bash" type unit, a piston-like plunger operating from an eccentric, forces the water through the perforated screen plate. The upward movement of the water through the screen from air pressure or plunger-activated water pressure is referred to as the "pulsion" stroke while the downward water movement is termed the "suction" stroke.

To better understand the operation, consider first a single cell. This cell is filled with water until the surface rises almost to the air slide valve connection. The raw coal to be separated is put on the jig screen, compressed air is supplied to the slide valve, and the eccentric shaft started turning over. During half the stroke of the slide valve compressed air is admitted into the closed end of the one leg of the cell. This air exerts its pressure on the surface of the water and forces it down through this leg, around the turn in the hutch, up the other leg, through the jig screen and then through the bed of raw coal. This is the pulsion stroke. At the end of this half of the valve stroke the compressed air is cut off and remains cut off during the second half stroke. In the second half stroke the valve opens a passage for the release of the compressed air in the closed leg of the cell and exhausts it to atmosphere. The surface of the water in the open leg, having been raised above that in the closed leg by the force of the air, now falls back downward and tends to equalize with the surface in the closed leg. This is the suction stroke. This double stroke of the valve, with the resulting pulsations of the water, is repeated with each revolution of the shaft.

At this point, without going into the theory of jigging, it must be accepted that the falling velocity of coal is less than that of the heavier refuse and, therefore, during the pulsion stroke, the coal will rise farther in the bed than an equivalent particle of refuse. During the suction stroke the refuse will fall farther than an equivalent particle of coal. After a sufficient number of pulsations the purest coal will be concentrated at the top of the bed while the refuse will be at the bottom on the jig screen. There will not be any sharp interface above which there will be coal and below which there will be refuse. There will be a gradual gradation from the lightest, purest coal in the top stratum to the heaviest refuse at the bottom. Figure 7-28 displays the various stages in the stratification process.

Any quality of clean coal can be removed by scraping off layer after layer starting from the top. The quality of the aggregate will become lower and lower as more layers are added.

The U-shaped container as a whole acts as a passageway through which the pulsations from the sealed chamber are delivered to the materials resting on the screen. The

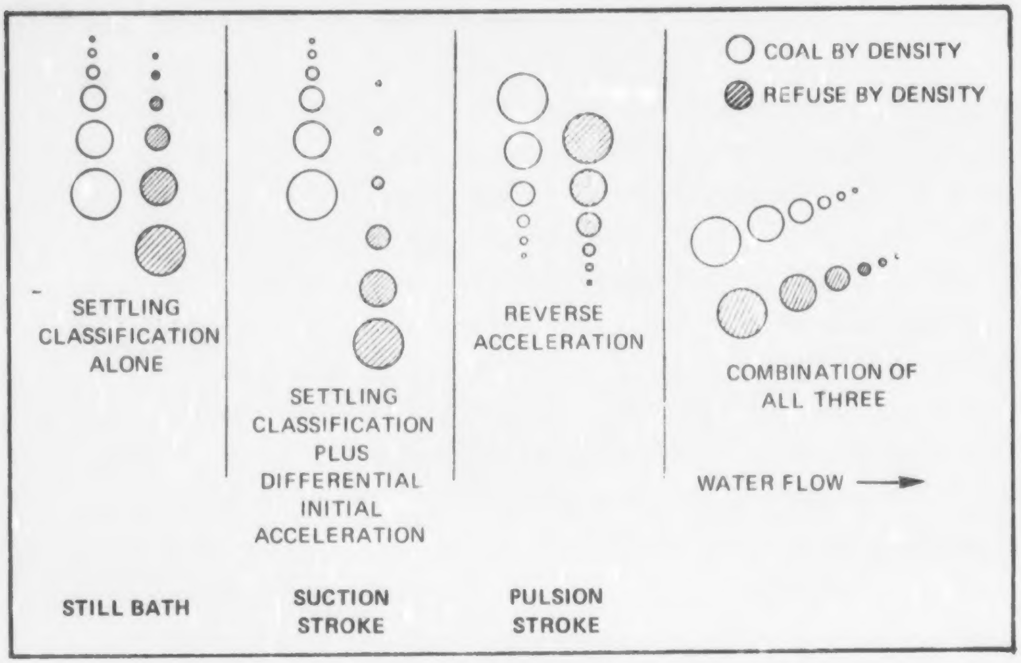


Figure 7-28
Various Stages in the Stratification Process

jig box is divided vertically into compartments. The compartments are separated by fixed weirs which control the flow of the float strata. A compartment is actually a complete jig in itself including means of separating and removing the lower particle layers from the screen bed. Thus, a multi-compartment jig is really a series of two or more jigs designed to produce multiple products and function as a primary separator (remove heavier refuse) and a secondary operation (produce a quality coal product), i.e., the float material from one compartment feeds into the second compartment.

In turn, each compartment is divided into two, three or four cells. The number of cells is varied according to the difficulty of separation, each representing a "stage" of washing. Each cell can be controlled separately as regards to the pulsations and water introduction. Water is introduced continuously into each cell to replace that removed with the products and to fulfill other functions. The water introduction plays a major role in the jig operation and its volume is an important control parameter.

The support screen normally has 1/4" aperatures, although openings as large as 1 1/4" have been reported. The size of the openings is used as a means of modifying suction intensity or to offer some control of the fine particle sizes when the feed is high in flaky impurities.

Within the solids discharge location at one end of each compartment, the two layers (clean coal and refuse) are split and a refuse ejector withdraws the bottom layer (refuse or middling) as it is collected on the screen plate and drops it into the boot of an elevator adjacent to the hutch compartment. The elevator with its boot is built integral with the jig. The adjustment of the refuse gate height, the refuse withdrawal rate and a float control determines the refuse separation. The rate of refuse withdrawal is usually controlled by a float located in the jig bed. The upper layers containing quality coal pass over a weir into a delivery sluice for dewatering.

A control (float or other device) is immersed in the jig bed at a point near the level where the division of the coal strata from refuse strata occurs. It represents an automatic control sensor. The float functions as a hydrometer that measures the specific gravity of the coal-refuse-water mixture at a selected level in the jig bed. The measurement is usually made at the peak of the pulsion stroke. The specific gravity measured is a function of the refuse level in the jig bed. The float height level varies with specific gravity of the bed at the set location and actuates suitable mechanical devices to change the rate of refuse withdrawal. The floats are subject to a high wear rate.

Although there is much similarity in plunger and Baum-jig cycles, there is a significant difference which distinguishes them. Those aspects of a Baum jig which control air volume or pressure may be related to the nature of the strokes in a plunger-type jig. In the pulsion stroke of a plunger jig, it is doubtful if the mechanical attainment of the initial rapid impulse desired to lift the bed is fully adequate or is followed by a sufficient speed reduction to allow optimum bed opening and direction reversal of the flow. Too slow a plunger speed may retard downward bed motions thus reducing efficiency of the suction stroke. During the suction stroke in a Baum jig, the water and particle mass is moved solely by gravity; but control can be exerted by the rate of air release and water introduction, whereas the configuration of the eccentric or cam activating the plunger governs in the mechanical type. It is the control capability of the "back suction" which is unique in the Baum concept. As regards densimetric stratification, back suction is always objectionable as it modifies particle settling rates and enhances the compact bed formation. Thus, the cycle control tends to be more versatile and effective in an air-operated jig, which results in a relatively low capacity per unit screen area for the plunger jig and also a closer adjustment to attain equivalent separations. The Baum jigging action is obtained by delivery of a suitable volume of air at the proper pressure to the air receiver. As air is admitted on the pulsion stroke of a Baum jig, the air pressure produces a sharp upward movement of the water, since water compresses very little. When the incoming air is stopped, the air in the pulsion chamber continues to expand, simultaneously reducing the air pressure. During this reduction in air pressure, the water movement decreases and the particle bed opens from the bottom upward. The air-pulsation principle permits a closer approach to unhindered stratification between pulses, thus a more effective cleaning of all sizes. It is the nature and frequency of the jig cycle which achieves the desired particle stratification.

7.3.4 Hydraulic Coarse Coal Cleaning Equipment

Generally speaking, the fundamental features of jigs were known from antiquity onward, but little progress was made until recent times. The principal features of jig design that require attention are:

- Development of a proper jigging cycle, with ready adjustments as to length of stroke, duration and character of cycle.
- Even transmission of jigging motion from point of application to point of utilization of motion.
- Use of suitable bed material or ragging, whenever a hutch product is secured.
- Rapid evacuation of strata and conveyance from jig.
- Design with respect to the relative tonnages of heavy and light strata.

There are a number of hydraulic jigs commercially available. Several of these units are addressed in detail.

- McNally Norton Standard Washer--This washer as depicted in Figure 7-29 is a fully automatic unit, which stays in balance at a pre-determined specific gravity separation point despite variations in tonnage or characteristics of the incoming feed. It is a Baum-type jig using air to distend the bed intermittantly to effect stratification of both coal and refuse on the limits of specific gravity.

Operation of the washer is simple and positive. Raw coal is cleaned in two stages. A primary separation at the feed end of the washer removes the heavier refuse material. The secondary compartment divides the coal into a bottom layer of middlings on which rides a second layer of quality coal. At the discharge end the two layers are split, the good coal passing into a primary sluice. Middling materials are discharged separately for rejection or reprocessing; or they may be delivered as a second grade of coal.

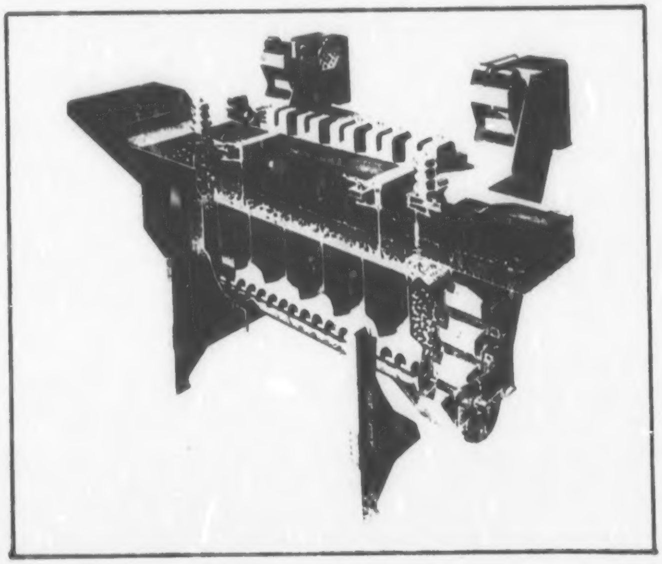


Figure 7-29
McNally Norton Standard Washer
Source: McNally-Pittsburg Manufacturing Company

A primary advantage of McNally Norton washer is its ability to handle fluctuating tonnages, and varying qualities of raw coal feed while delivering a continuously uniform product. Tonnages that can be handled by one washer range up to 500 tons per hour.

- McNally Mogul Washer--Illustrated in Figure 7-30, this washer is designed primarily to provide an automatic Baum-type jig that can easily handle flat slabby refuse. Forward flow of the coal and reject increases capacity in the primary end of the Mogul washer.

Any stratification made in the first two cells of the secondary compartment is not distended or interrupted, but is further stratified in the remaining two cells, giving a cleaner more efficient separation. The bed is maintained at a selected depth by the float mechanism which varies the opening of the discharge gates to match the volume of reject in the washer feed.

The evacuating gates are air operated. The gates consist of multiple pivot fingers. These discharge gates are equipped with a perforated stainless steel plate through which the upward impulses pass from the adjacent washing cell. The washer is available in capacities up to 600 tph for some coals.

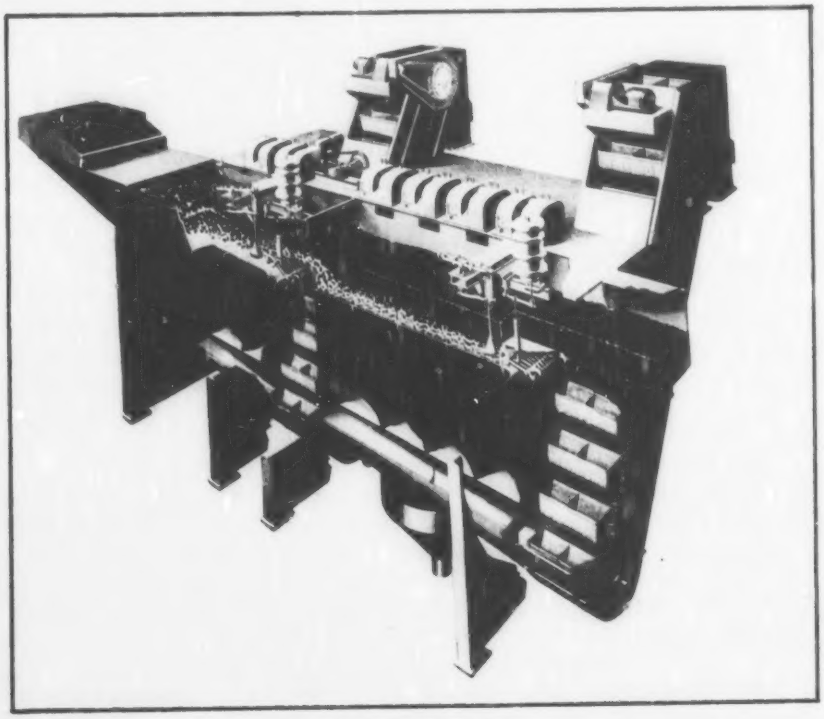


Figure 7-30
McNally Mogul Washer
Source: McNally-Pittsburg Manufacturing Company

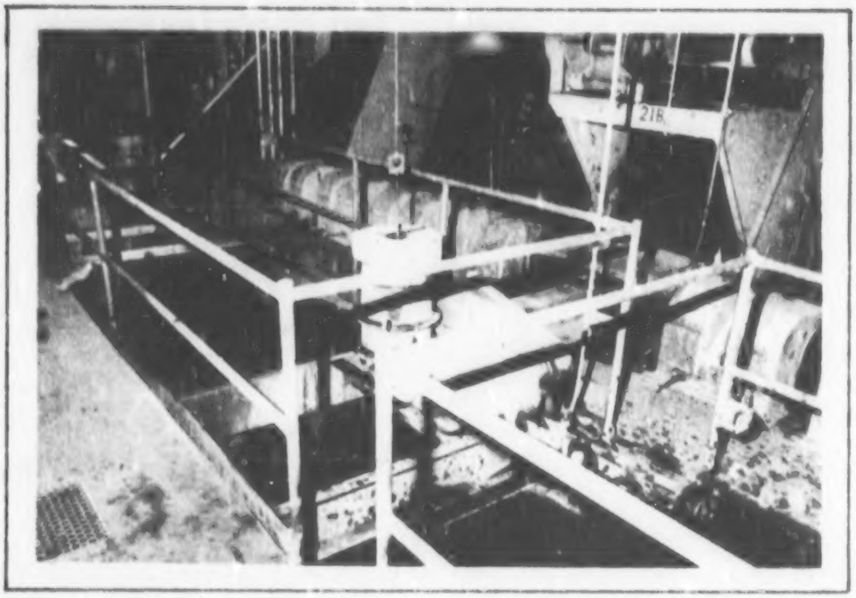


Figure 7-31
McNally Mogul Washer as Observed in a Preparation Plant

- McNally Giant Washer--The tonnage capacity has been greatly increased by rearranging the washing cells. The washer has a total of 180 sq. ft. of effective washing area, providing 20% greater washing area, and a tonnage capacity of 750tph. The combined washing compartments are 10 ft. wide. The primary compartment consists of two cells while the secondary compartment consists of four cells. Any stratification made in the first two cells of the secondary compartment is not distended or interrupted, but is further stratified in the remaining two cells giving a cleaner, more efficient separation. This unit is shown in Figure 7-32.

  Adjustable positioning of the pistons along the push rod provides a wide range of adjustment in the intake and the exhaust interval of each cell. The various speed drive permits setting the impulse frequency to suit the separator requirements while maintaining positive synchronism of the impulse to each cell. The impulses to the primary cells are directly and positively opposed to those of the secondary cells. Spiral conveyors for handling the gob material have been eliminated.

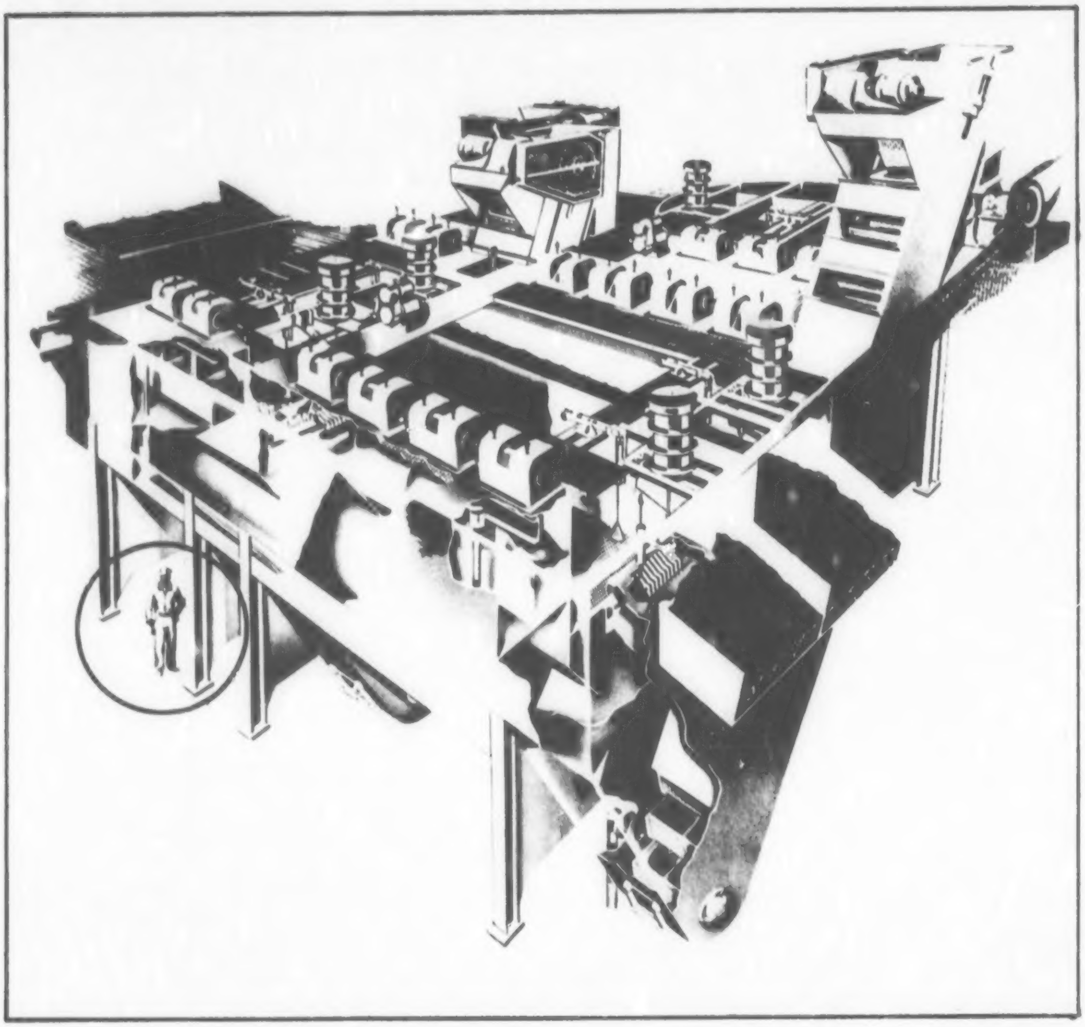


Figure 7-32
McNally Giant Washer
Source: McNally-Pittsburg Manufacturing Company

- Batac Jig--To improve the performance and to obtain greater capacities than available with standard jigs, recent radical modifications have been made in the design and operation of this new jig called the Batac.

  In the Batac jig the principle of causing the pulsations to the raw coal feed in the water medium is the same as in the Baum jig. However, the methods of air distribution, the pulsation action of the air by new type of valves, and the bed control have been greatly improved and automated.

In the Baum jig, air under pressure is forced into a large chamber on one side of the jig vessel, with the air pulsated by the action of sliding or rotary valves (see Figure 7-33). This creates a pulsating and suction action in the jig water, thereby causing a stratification of the particles that are to be separated in accordance with their relative specific gravities.

Distribution of this force beginning on one side of the jig frequently causes unequal variations in the jigging action over the width of the jig bed and, therefore, unequal variations in the stratification within the bed.

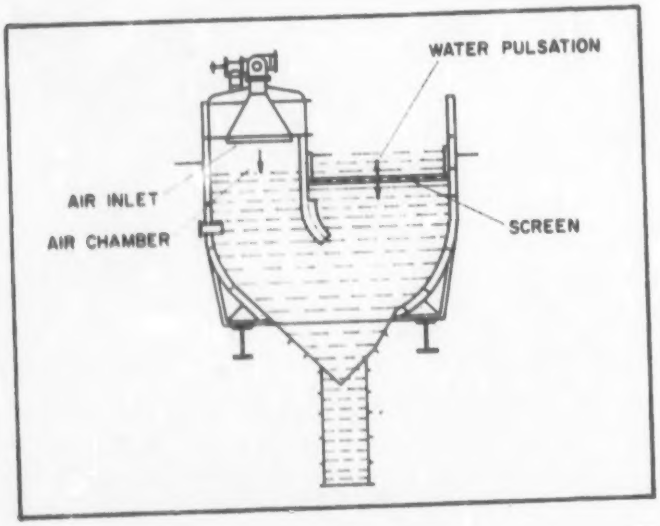


Figure 7-33

Baum Jig Cross Section

Air is forced under pressure into an air chamber on one side of the jig vessel and is pulsated by action of sliding or rotary valves.

In the Batac jig, there is no side air chamber. Rather, it is designed with a series of multiple air chambers, usually two to a cell, extending under the jig screen for its full width, thus providing for a uniform air distribution.

This principle of air distribution originated in Japan and is used in their Tacub jig. The Batac, derived from the words Baum and Tacub, was developed using this principle by Humboldt Wedag of Germany.

Figures 7-34 and 7-35 illustrate a six-cell three compartment Batac jig. The heavy specific gravity material in the coal discharges through the screen plate perforations and at the end of

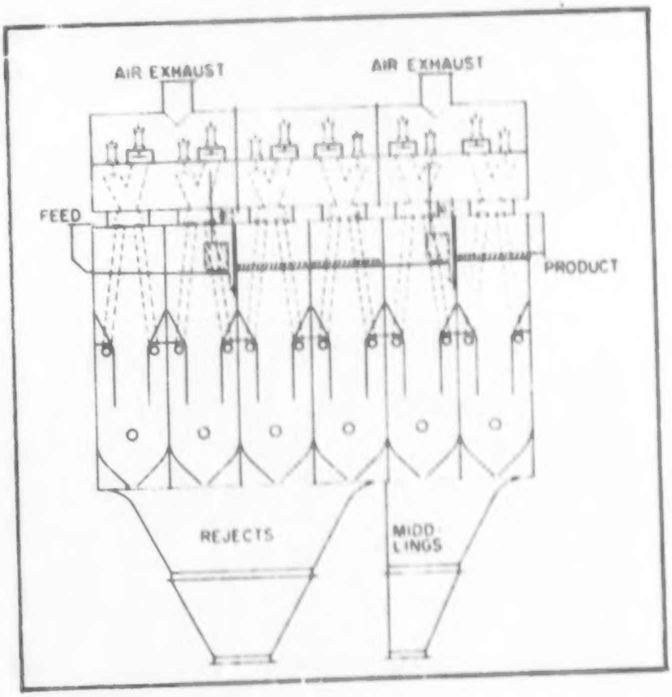


Figure 7-34
Side View Cross Section of Batac Jig

Jig is designed with a series of multiple air chambers, usually two to a cell, extending under the jig screen for its full width so as to provide uniform air distribution.

the compartments through shale ejectors. Primary rejects or refuse may be discharged by the bucket elevator from either the first compartment alone or, depending upon the quantity of heavy refuse to be discarded, from both the first and second compartments.

Secondary rejects may discharge to the second bucket elevator, either from the second compartment or only from the third compartment. The secondary rejects may, if the character of the material warrants, either go to final reject, be returned back to the jig feed for recirculation, or may be classed as middlings or secondary product. The secondary rejects may also be recleaned in a heavy-media system.

This latter step may be desirable in some very difficult coals containing a high percentage of near gravity material or if it is necessary to clean the coal at a low specific gravity of separation. This retreatment, if required, involves only a relatively small tonnage of the total jig feed.

The standard Baum jig uses either piston or rotary type of air valves. The Batac jig uses a flat disc design, which provides a sharp cutoff of the air input and exhaust. These valves, both for inlet and outlet of air, can be infinitely varied as to speed and length of stroke. The ability to vary the cycle characteristics of the pulsation and suction is of immense value in opening and closing of the bed to obtain proper stratification in the bed as the raw coal characteristics change in terms of size consist and/or variable densities.

These air valves are operated from an electronic solid-state instrument cabinet generally installed in the plant control center.

The electronic components for controlling the action of the air valves in the Batac jig (whose speed is measured in milliseconds) are in modular slide-in form and, if a malfunction does occur, they can easily be replaced in a few moments.

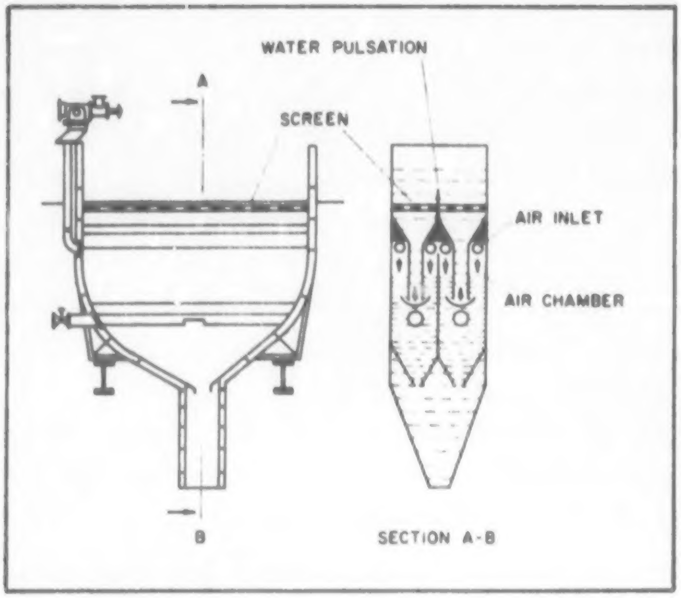


Figure 7-35

Batac Jig Cross Section

Heavy specific gravity material in the coal discharges through the screen plate perforations and at the end of the compartments through shale ejectors.

For controlling the bed level of the stratified material in the jig, a number of floats are installed along the width of the jig in each compartment. These floats are automatically controlled by inductive coils which can be set to measure the various densities of separation. They trigger hydraulically operated refuse ejector valves which increase or decrease the bed level, as required.

In case of a plant stoppage or loss of feed to the jig, a float mechanism near the feed end of the jig is used to bypass the jig air used for pulsation. This prevents a disturbance of the jig bed and avoids the usual misplaced material which would otherwise occur if the jig is operated without raw coal input.

7.3.5 Separation of Intermediate Size Coal

The current emphasis on cleaning the smaller coal particles is the result of new mining techniques and equipment which produce a finer size of ROM coal, a result of the need to crush coal to further reduce its size prior to washing to liberate coal-associated impurities such as pyrite (only through the liberation of these impurities can an acceptable final product be provided at the maximum yield), and a result of ever-increasing production costs which require the maximum recovery of clean salable coal to justify the existence of the industry. As pointed out in previous discussions, the cleaning of the smaller coal sizes is inherently more difficult and the preparation costs increase with decreasing size.

The differentiation between intermediate and fine size coal cleaning equipment becomes very complicated and somewhat arbitrary. On an industry-wide basis, coal cleaning equipment is classified as either coarse or fine coal cleaning equipment. However, for the purpose of clarification this disucssion will divide the "fine" coal cleaning equipment into intermediate size coal cleaning and fine size coal cleaning equipment. The intermediate size coal cleaning equipment addresses primarily 3/4" x 0, although some of the equipment discussed has top sizes in the range of 1¼" and other generally address ¼" x 0 coal. The fine size coal cleaning equipment discussion will be restricted to the froth flotation of the ultra fine coal sizes primarily 48-mesh x 0. A complete understanding of the interdependence and inter-relationships of both intermediate and fine size coal cleaning equipment may be obtained from a review of the flow charts discussed in Chapter 11.

The intermediate size coal cleaning equipment may be classified into four general groups. These are:

- dense media cyclones,
- hydrocyclones,
- wet concentrating tables and
- fine coal launder and jigs.

7.3.5.1 Dense Media Cyclones--Generally speaking, crushing raw coal tends to free particles of good coal from particles of impurities. However, with the reduction of particle size below ¼", the difficulty of gravimetric separation increases. This is so, because the time required for any particle to settle in water is dependent upon its specific gravity and the resistance of the water to the settling of that particle. The larger the particle, the faster the sinking rate in proportion to a given fluid resistance-mass ratio.

Conventional jigs take advantage of this fact with the impulses and free water to form strata of different specific gravity material. As particles become smaller, settling rates are increased. The settling time of fine particles can be reduced by the application of force to them. Figure 7-36 depicts a basic dense media cyclone and the idealized flow pattern within the cyclone.

In a cyclone, this force is brought to bear centrifugally by admitting raw coal and water under pressure into the cyclone tangentially near the top. The resultant forces are centrifugal. In a typical cyclone the centrifugal force acting on a particle in the inlet region is about 20 times greater than the gravitational force in a static bath. As the feed descends in the conical section of the cyclone, the centrifugal force is further increased and may reach to over 200 times gravity at the apex. At this point, the cyclone has accomplished a size classification of the particles resulting from the fact that under centrifugal force, the larger particles will travel to the perimeters of the cyclone and the smaller particles will remain near the center.

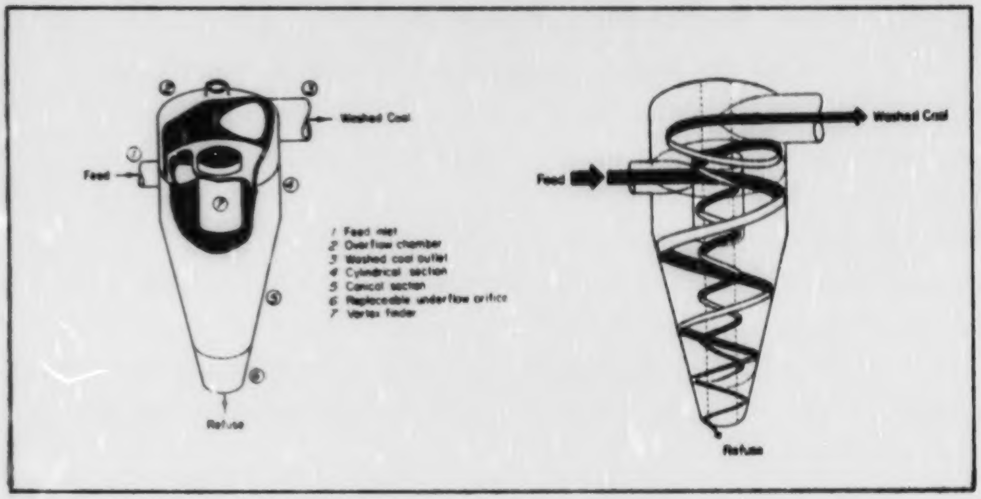


Figure 7-36
A Dense Medium Cyclone and the Idealized Flow Pattern Within

To achieve a gravimetric classification, the water is made dense by the addition of fine-ground magnetite with the result that the particles having a higher specific gravity are forced to the permiter of the cone and passed out through the apex as refuse, while the particles of lesser specific gravity remain near the vortex finder and pass out through the top of the cone as clean coal. In conventional cyclones, the mass generally is admitted at a tangent. Gravimetric classification commences in the feed line and arrives in the cyclone partially separated, leaving for the cyclone itself only the final gravimetric separation.

The general flow pattern of the medium in a cyclone, shown in Figure 7-36 consists of a descending vortex that originates at the inlet and progresses through the cyclone to the underflow outlet. As the descending vortex passes down the cyclone, part of the fluid peels off toward the center of the cyclone to form an ascending vortex. This ascending vortex, in turn, surrounds a cylindrical air core that encircles the entire longitudinal axis of the cyclone. An additional factor that influences the separation is the progressive increase in specific gravity of the medium as it descends toward the apex. This increase occurs because the centrifugal force also tends to force the medium particles toward the cyclone wall. Therefore, they are preferentially caught in the descending vortex resulting in progressively higher concentrations of medium particles as the apex is approached. As might be expected, then, the specific gravity of the medium flowing through the underflow orifice is higher than the specific gravity of the circulating medium. Conversely, the specific gravity of the medium passing through the overflow orifice is less.

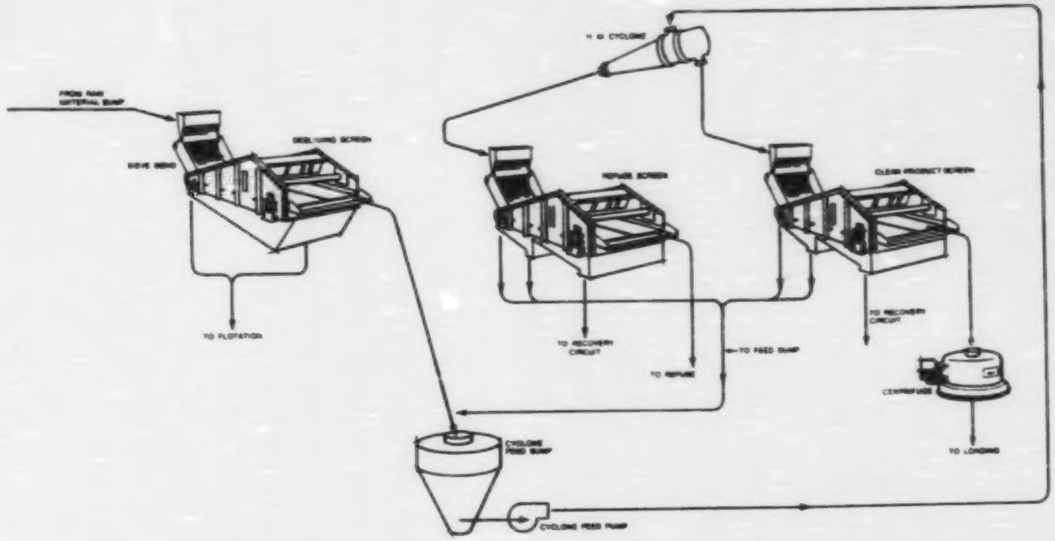
If there is some mystery to cleaning coal by mixing it in a dense fluid and whirling it around in a cone, it is understandable. The paths followed by the coal and impurity particles in a cyclone have been studied by observation in a glass or clear plastic cyclones and are still not fully understood. The refuse particles flow to the wall soon after they enter the cyclone. They are entrained in the descending vortex and are discharged through the underflow orifice. The coal particles are also initially entrained in the descending vortex. Some of these migrate to the ascending vortex in the upper part of the cyclone. Curiously, a large number of the coal particles descend well into the conical part of the cyclone before they are trapped by the ascending vortex. This behavior has been explained by postulating a barrier of high specific gravity that is due to circulating medium particles in the lower part of the cyclone. When the descending coal particles reach this zone, they migrate toward the central air core. They are then caught in the ascending vortex and pass through the overflow opening. The existence of a barrier, however, cannot entirely explain the path of the coal particles because observation of the coal particles in a glass cyclone using an organic heavy liquid shows that they behave similarly; that is, many coal particles descend well into the conical section before they migrate to the ascending vortex. Clearly, a heavy liquid is homogeneous and a barrier cannot be present, yet the separation is very sharp. It is also interesting to note that the specific gravity of separation is almost always higher than the specific gravity of the medium when using either a heavy liquid medium or a magnetite dense medium.

The dense media cyclone is generally selected for low specific gravity separations where there are high accumulations of near gravity materials. Both fine and coarse coal medium systems can be used advantageously and economically when combined. The top size that any cyclone cleaner should be fed depends upon the design of the entire coal washing plant. If a washing plant uses either coarse dense media or jig washing in combination with a cyclone, the selection of the cyclone depends upon the point of separation most economical for the highest recovery of fine and coarse coals. That point of separation may be anywhere from ¼" to 1½". Generally, it is not economical or advantageous to go to sizes above ½" in cyclone washeries if both coarse and fines are washed. If a cyclone washer is to be the only washer installed in the plant, more than likely the feed size would be approximately 1½". This top size, again, depends upon the individual washability characteristics of the coal which indicates the proper top size where a maximum yield will result when obtaining a predetermined ash content.

A number of factors relate to the proper selection of cyclones for any given problem. The size and number of cyclones required for any given situation depends upon the size of the coal to be treated in the cyclone, the wash coal recovery expected and the suitability of a particular bank of cyclones to a particular situation. Cyclones could be offered in many different sizes to accomodate each and every problem. However, most manufacturers have found it practical to offer cyclones in two or three sizes, such as 18, 20 and 24 inches. The size relates to the inside diameter of the inlet chamber. Smaller sizes are available. Larger sizes are being studied. Regardless of the size most economical and selected for the particular problem, preparation engineers are capable of designing the entire circuit to suit each and every application. The normal design capacity for 20 inch cyclones is approximately 50 tons per hour and for a 24 inch cyclone is approximately 75 tons per hour. The normal refuse design capacity is about 60% of the cyclone feed capacity. Figure 7-37 depicts a typical dense media cyclone circuit. A media recovery circuit is depicted in Figure 7-16.

The cyclone is useful for washing coal only when it is properly integrated into a complete coal washing system for fine coal. The effectiveness of any cyclone is critically dependent upon the control of the dense medium itself and is economically feasible only when the magnetite used in the dense media can be reused with a minimum of losses. The largest loss of magnetite in any plant generally occurs from magnetite adhering to the refuse and to the clean coal product. Some losses also occur with the tailings from the magnetic separator. In preparation plants where large tonnages are concerned, additional equipment is included in the plant for recovery of very fine coals (½ mm x 0), i.e., flotation cells, filters and thickeners. Since added equipment is used in these more complex plants, it is possible to recover magnetite more efficiently. For example, the tailings from the magnetite separators may be fed to the froth flotation circuit where any residual magnetite will report as refuse to the flotation cells. If a magnetic separator is used on the thickener underflow (flotation tailings) added magnetite may be recovered. Additionally, in some heavily equipped plants, the use of a centrifugal dryer on the clean coal rinsed product may be added. By the addition of a spray in the centrifuge, more magnetite is rinsed from the clean coal which reports to the effluent from the centrifuge. This, in turn, is directed to the flotation cells for recovery.

7.3.5.2 Hydrocyclones--A hydrocyclone is very similar in construction to a heavy media cyclone but is less efficient without the magnetite. Essentially, it is a cylindro-concial unit with an included apex angle of up to 120°, much greater than the included apex angle of the dense media cyclone which is around 14°. The hydrocyclone also has a longer vortex finder than does the dense media cyclone or the hydraulic or classifying cyclone. Figure 7-38 depicts a cross section view of a typical hydrocyclone and demonstrates the separation process. The coal and water slurry is introduced tangentially and under pressure



Source: Roberts & Schaefer Company

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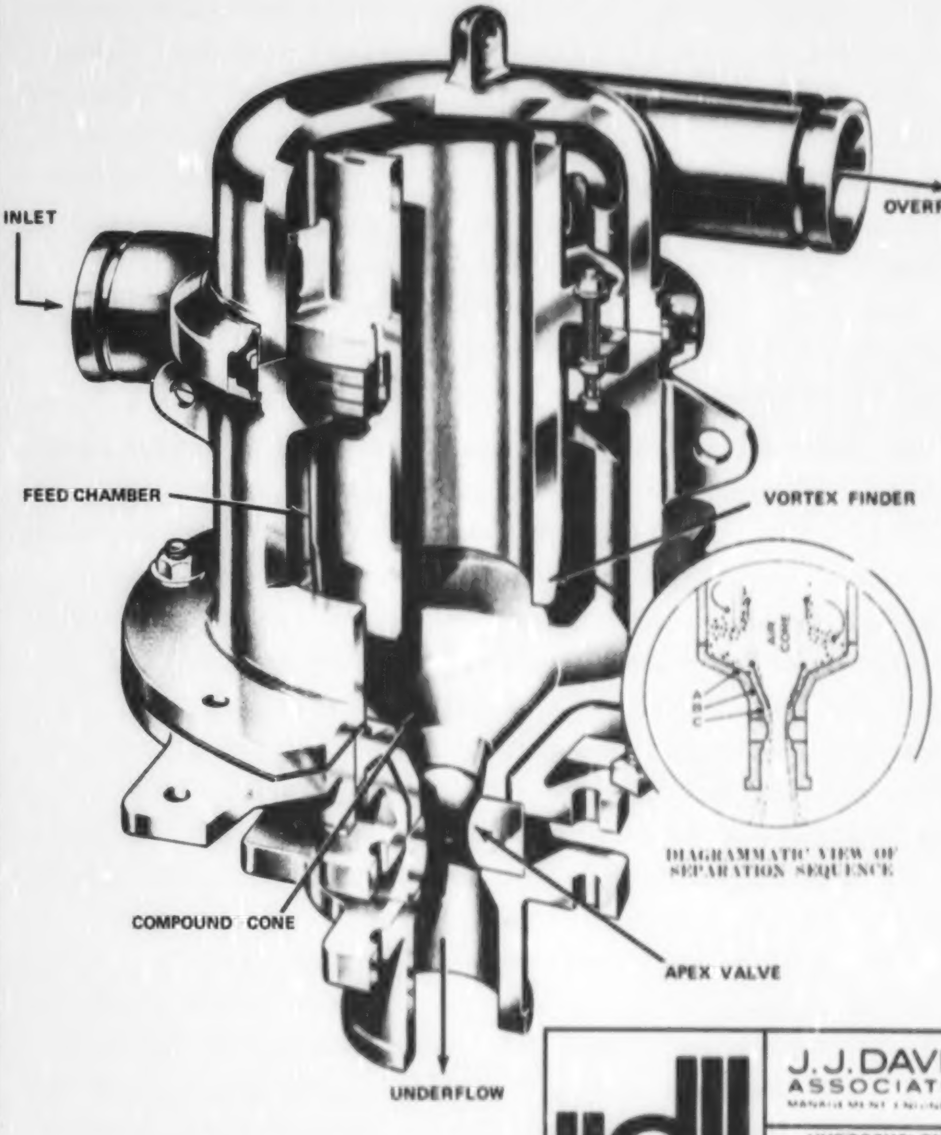
Typical Dense Media Cyclone Circuit

Figure 7-37 DCN

into the central feed chamber. The cycloidal configuration of the inlet imparts an initial circular motion to the slurry and initial centrifugal separation of the particles begins. As the slurry moves downward into the conical section, the centrifugal force acting on the particles increases with the descreasing radii.

Particles of different sizes and specific gravity form a hindered settling bed in the first conical section (A) (refer to Figure 7-38), and the separation process takes place in three separate steps. Light, coarse particles are prevented from penetrating the lower strata of this bed by the coarse heavy fractions (middlings and refuse). As a direct result, the water as it passes from the periphery of the hydrocyclone towards the vortex finder erodes the top of the stratified bed and removes the light coarse particles via the central current around the air core and up the vortex finder.

The remainder of the bed which has not measurably lost its stratified character is forced into the second conical section (B) by the mass of new material entering the hydrocyclone. As indicated, the centrifugal force is considerably increased and additional stratification and erosion takes place. As the lighter pure coal particles are removed, the heavier "middling" coal particles are exposed. The lighter of these middling particles are swept up and discharged via the vortex finder. The heavy middlings that spiral upward in the central current of departing water may by-pass the orifice of the lower vortex finder due to their higher specific gravity. Consequently, the coarse heavy middlings fraction tends to recirculate to the stratified bed and finally enters the third concial section (C).



SOURCE: McNALLY–PITTSBURG

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HYDROCYCLONE
CROSS-SECTION &
FLOW DIAGRAM

Figure 7-38 | DCN

In this last and smaller conical section, the bed is finally destroyed as coarse particles fan out along the wall in a single layer, exposing the small particles that so far have been shielded from the central current. The central current of departing water in this smallest section is relatively weak, having spent itself in the preceding sections. The upward current that remains separates the small particles from the remainder of the material, with preference for those of low specific gravity. Thus, the fine, light particles are finally discharged up through the vortex finder by a process of elutriation. The fine and coarse refuse is discharged through the apex.

The specific gravity of separation of a hydrocyclone, and hence the clean coal ash content, is regulated in general by varying the dimensions of the discharge orifices. For example, the clean coal ash content can be reduced by decreasing the diameter of the vortex finder or increasing the diameter of the underflow orifice. To achieve the same result, the length of the vortex finder can be decreased. Generally, the vortex finder length is not changed, but the distance that it projects into the conical section of the cyclone is varied by adding or subtracting shims between a flange on the vortex finder and the bottom of the overflow chamber. This has the same effect as changing the length of the vortex finder. Capacities of the units are affected by the diameter of the vortex finder and limited by the diameter of the apex. Generally, a single stage hydrocyclone system can produce a clean coal essentially free of misplaced refuse; however, a significant characteristic of the hydrocyclone that detracts from its performance is that a substantial portion of the low specific gravity particles report to the refuse product. Therefore, two-stage treatment is recommended and is especially applicable for minus ¼ inch or minus 3/8 inch raw coal. For example, the raw coal is first treated in a primary hydrocyclone which produces a finished clean coal product. The refuse is recleaned in a secondary hydrocyclone. The clean coal from this secondary hydrocyclone joins the clean coal from the primary unit to form the final clean coal product; the refuse from the secondary hydrocyclone is the final refuse product.

The separations that are obtained in a hydrocyclone are not nearly as sharp as those that are characteristic of the dense medium cyclone. Therefore, the hydrocyclone is not applicable for difficult-to-clean coals or for separations at low specific gravities. The hydrocyclone may be especially applicable for treating minus 28-mesh coal if the coal is not amenable to flotation. If fine pyrite is present in the feed, the hydrocyclone is reported to be superior to flotation for lowering the sulfur content of the clean coal.

The coarser particles of an easy-to-clean coal with a top size of ¼ inch or 3/8 inch can be cleaned about as efficiently in a two-stage hydrocyclone as on a concentrating table. However, the concentrating table cleans the finer particles much more efficiently than the hydrocyclone and, although the hydrocyclone takes up considerably less floor space than the concentrating table, the large quantities of water and power required for operation of the hydrocyclone must be weighed by the preparation engineer.

7.3.5.3 Wet Concentrating Tables--It is estimated that 75,000,000 tons of metallurgical coal are cleaned annually on tables in the United States alone. In recent years, the trend has been toward cleaning of utility coal which formerly was burned with little or no preparation in electrical power generating plants. Strict regulations concerning SO_2 emissions have helped to increase the use of tables to remove pyritic sulfur from raw coal before the coal is burned.

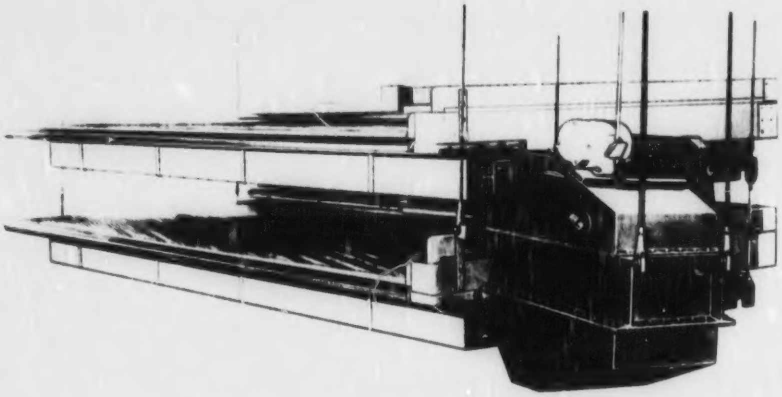
Many modern coal preparation plants in which tables are used feature dense media vessels to clean the coarse fraction and froth flotation to clean the extreme fines. The 3/8" x 0 or ¼" x 0 raw coal is run across fixed sieves separating at about 48-mesh, and the ¼" x 48-mesh fixed sieve overflow goes to double-deck tables while the 48-mesh x 0 underflow reports to flotation cells. This is a simple flow-sheet and produces good results, so long as the sulfur content of the 48-mesh x 0 fraction is not a problem (the pyrite will float right along with the coal). This problem can be overcome by sending the fixed sieve underflow to classifying cyclones ahead of the flotation. The 48-mesh x approximately 100-mesh cyclone underflow, which contains free pyrite down to about 325-mesh, then rejoins the ¼" x 48-mesh fraction at the table distributor. The tables will efficiently provide ash reduction through 100-mesh while simultaneously rejecting free pyrite down to 325-mesh. In the meantime, the -100-mesh classifying cyclone overflow has gone to flotation with most of the sulfur already removed.

Today's modern wet concentrating tables are the natural outgrowth of an evolutionary process that began years ago. The introduction of suspended, multiple-deck tables in the late 1950's and early 1960's by the Deister Concentrator Company has been the latest significant development in the manufacture of concentrating tables. This has eliminated to a large extent two of the primary disadvantages of concentrating tables, namely the need for large amounts of floor space and the need for massive concrete foundation piers and flooring to absorb the impact of the drive mechanisms. Figure 7-39 depicts the suspended, multiple-deck tables in their two most common configurations.

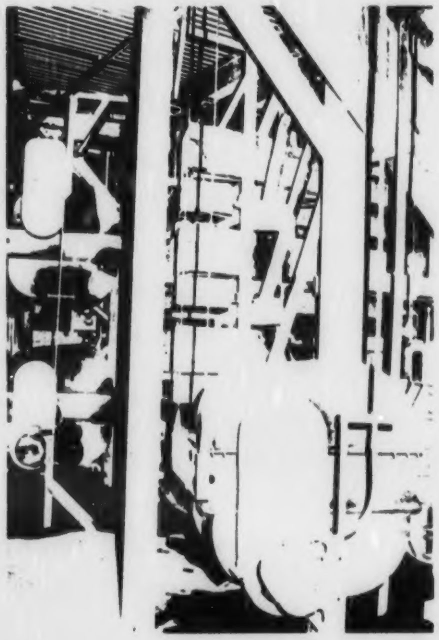
The table employs the principle of flowing a mixture of coal and water over a series of riffles which are shaken rapidly to effect a separation of the coal by particle size and specific gravity. Basically, the table consists of a pair of steel channels upon which is mounted a rubber-covered deck and a drive mechanism. The flat, rhomboid-shaped deck is approximately 17 feet long on the clean-coal side and 8 feet long on the refuse side. It is supported in an essentially horizontal plane, but slopes enough (perpendicular to the motion of the deck) so that water fed along the upper long side will flow across the table surface and discharge along the lower clean-coal side. The deck is attached to a differential motion drive which gives it a quick return conveying motion, moving material lying on the table surface away from the drive end.

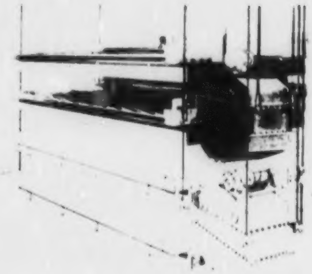
Attached to the rubber covering or the deck is a system of rubber riffles tapering toward the refuse end of the table and parallel to the direction of the conveying motion. Standard body riffles are approximately ¼ inch high at the drive end of the table. Between each set of three or four body riffles are high (over 1 inch at the drive end) "pool" riffles. These riffles form dams, behind which stratification of the bed occurs. Low-density particles ride over the riffles, reporting to the clean-coal side of the table; high-density particles are carried behind the riffles by the differential-motion drive to the refuse end of the table (see Figures 7-40 and 7-41).

At one corner of the long diagonal and above the deck is a feedbox with a slotted bottom to spread the feed onto



Source: Deister Concentrator Company, Inc.





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Typical Deister Table Installations

Figure 7-39 | DCN

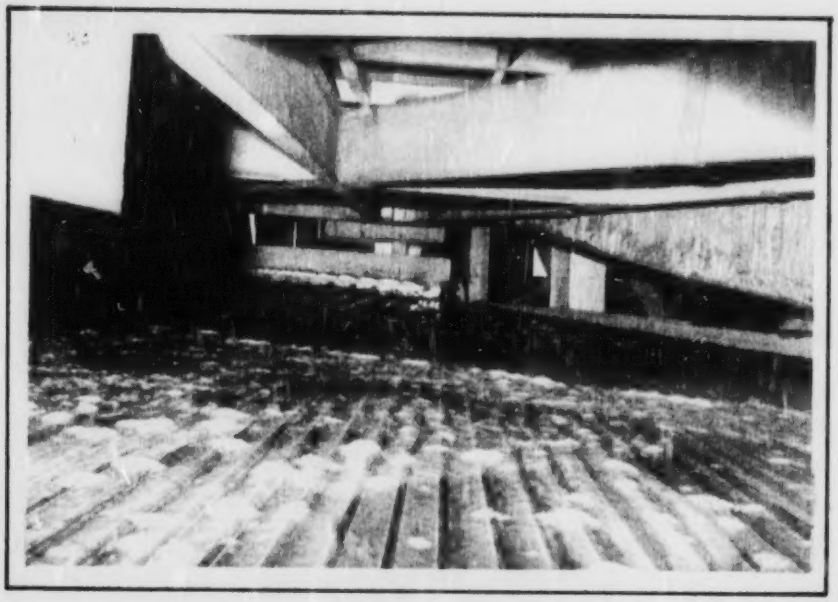

Figure 7-40
Rubber Riffles on a Concentrating Table

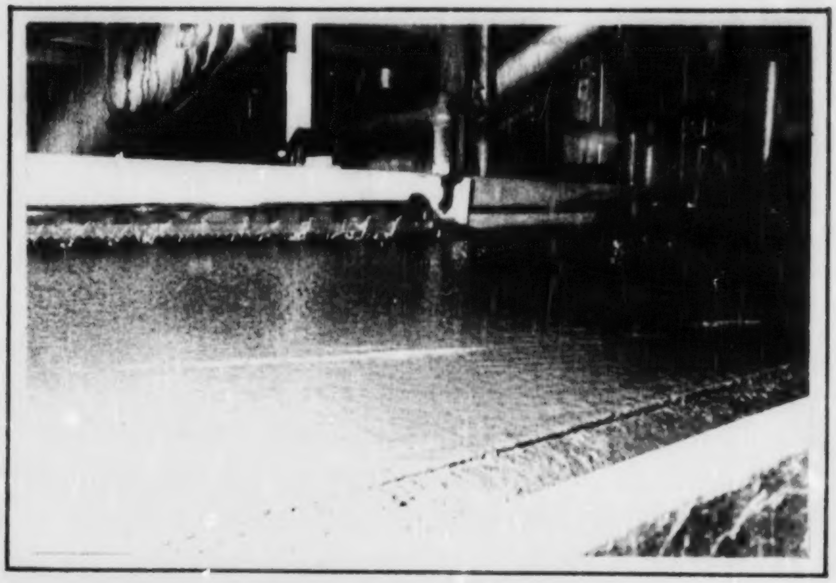

Figure 7-41
A Fully Loaded Table in Good Adjustment

the deck. Beside the feedbox and along that side of the deck is a trough, having adjustable gates through which the flow of dressing water to the deck is distributed.

Because of the reciprocating action of the table and the transverse flow of water, the pulp fans out immediately upon contacting the table surface. The upward slope of the table toward the refuse end, usually 1/8 to ¼ inch per foot, and the retaining effect of the pool riffles cause the slurry to form a pool near the feedbox. In the pool, the bed of material is several particles deep and substantially above the standard riffles and becomes the zone of primary stratification. In this zone the shaking motion of the deck combined with the cross current of water stratifies the particles by density, similar to the action of a jig washer.

Without doubt, the most fundamental principle of the table is the vertical stratification according to specific gravity that occurs behind the riffles due to the differential shaking action of the deck. The particles that make up the feed become arranged so that the finest and heaviest particles are at the bottom and the coarsest and lightest particles at the top. The smallest, heaviest particles are carried out by table movement toward the refuse end at a faster rate than coarse, heavy particles. The light-gravity larger pieces ride on the top layer of particles and flow on down the slope of the deck as a result of the cross flow of wash water at right angles to the shaking movement of the table. Since stratification and separation of particles are not complete as a result of any one riffle, a series of riffles is used, repeating the cycle of stratification and hindered settling from riffle to riffle, obtaining purer refuse products as the particles fan out and progress forward and downward over the table.

Conversely, the purer, cleaner coal is discharged at the drive end of the table.

As graphically portrayed in Figure 7-42, successive samples collected along the side and end of the table, starting at the head-motion end, show a steady increase in ash content and a steady decrease in the average particle size for each individual specific-gravity fraction.

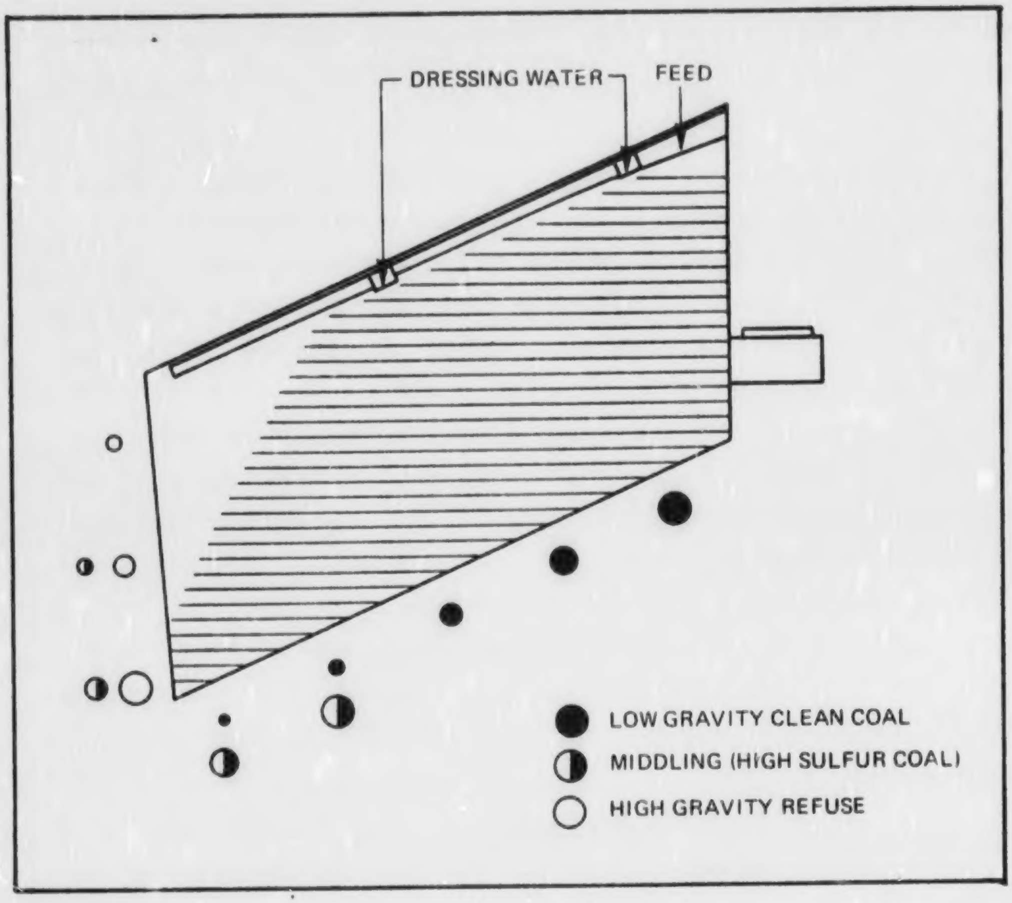

Figure 7-42
The Distribution of Table Products
by Particle Size and Specific Gravity

Concentrating tables are provided with a number of adjustments which should be used to obtain the best possible operation. Among these are: (1) speed, (2) length of stroke, (3) feed rate, (4) amount and distribution of wash water, (5) water-to-solids ratio of the feed pulp, (6) uniformity of feed, (7) riffle design, (8) side tilt and (9) end elevation. The reciprocation of the deck usually is 260 to 290 strokes per minute depending on the characteristics of the raw coal and the feed rate. If there are high percentages of refuse in the raw coal or if the feed rate is high, an increase in the frequency is required.

Closely related to the frequency is the amplitude. The amplitude and frequency are varied to maintain the mobility of the bed necessary for stratification while retaining the coal on the deck long enough for proper separation. In order to move large quantities of refuse material along the deck, an amplitude as long as 1¼ inches may be required. Conversely, the stroke may be less than ½ inch long when coals containing high percentages of near-gravity material are washed. The amplitude and frequency of the stroke are decreased as the amount of near-gravity material in the feed increases. A nominal 3/8 inch to 0 coal would require a stroke amplitude of about 3/4 inch and frequency of 275 strokes per minute. Generally, a fine feed will require a higher speed and shorter stroke than a coarse feed.

The cross slope and amount and distribution of dressing water to the table can be changed easily and quickly to compensate for minor variations in feed rate and composition. The cross slope is generally less than 5°, and the dressing water side of the table is higher than the clean-coal side. The feed dilution (water to solids ratio) normally used on a table is 2:1. The quantity of water used in the feed slurry varies, but the normal feed dilution is 40% solids for a ¼" x 0 size coal feed, and may drop to 33% solids for 3/4" x 0 coal.

Perhaps the most important of all table adjustments is the end elevation or the amount of upward inclination of the deck measured along the line of motion from the feed end to the discharge end. By creating a moderate slope that the high specific gravity particles will climb more readily than will the low specific gravity minerals, the separation is greatly improved. The high specific gravity minerals are forced to spread out in a thin, wide band which allows much sharper cuts to be made between clean coal, middling and refuse. The correct amount of end elevation varies with feed size and is greatest for the coarsest and highest gravity feeds. A nominal 3/8 inch to 0 feed would require 3 to 4 inches of end elevation.

Table capacity varies with the size consist, the percentage of reject contained in the feed and the washability of the table feed. Coarser feeds handle at higher rates than do finer feeds; and feed rates will be limited by the percentage of reject above 25%; and as the difficulty of cleaning decreases, feed rates can be increased. The majority of all installations in bituminous coal are on 3/8" x 0, or ¼" x 0 or deslimed fractions of some top size where, on coals of normal washing characteristics, capacity per double-deck table is 25 tph feed, i.e., 12½ tph per deck. For 3/4" or ½" top size, commonly handled when cleaning steam fuels, capacity of 30 tph per twin-deck table can be expected.

7.3.5.4 Fine Coal Launders and Jigs--Standard coal washing jigs, as discussed in Section 7.3.4, often treat the total size range of coal and retreatment of the smaller coal sizes is usually required. Although the fine coal washers have nearly died out in this country, Roberts and Schaefer is reintroducing a "fine coal jig". The Batac jig was developed by Humboldt Wedag of Germany and incorporates features of both the Baum jig and the Japanese Tacub jig. This jig has been discussed in detail in Section 7.3.4. The unit is designed to clean primarily 2" x 0 coal and it is hoped that the finer coal sizes will not have to be reclaimed as with other types of jigs or launders. At the moment, less than 6% of the intermediate coal sizes are effectively cleaned using fine coal launders or jigs and supporting data on the effectiveness of the Batac jig is still incomplete.

7.3.6 Separation of Fine Size Coal

As indicated in Chapter 8, other than just pumping away the black water from the plant, a number of methods are used to remove the ultra-fine coal and refuse solids from the recirculating water in a coal preparation facility. However, only one system is successful in separating only the salable coal from a -48-mesh size feed--froth flotation. As noted in various portions of Section 7.3 and in Chapter 8, a number of systems or pieces of equipment either concentrate or classify the finer sized particles for feeding to the froth flotation process. Figure 7-43 highlights a number of these entities.

Froth flotation of fine coal is a unique cleaning process when compared to every other separating system discussed in that the flotation process does not utilize the specific gravity difference between coal and refuse to effect a separation. In fact, the flotation process is not a physical process at all, but rather a chemical process that depends upon the selective adhesion of air bubbles to the coal particles and the simultaneous wetting or water adhesion to the refuse solids. The adhesion of

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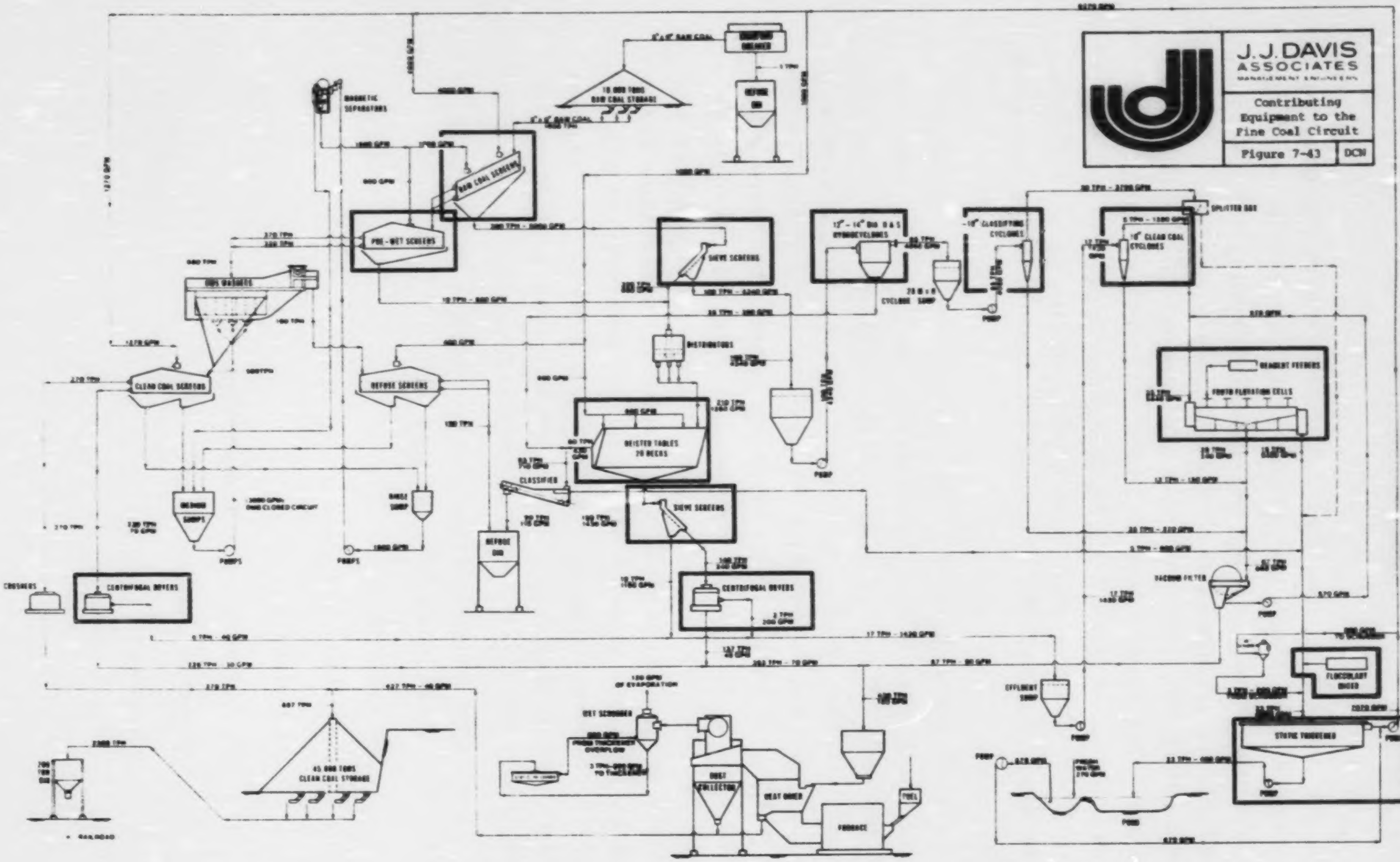

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Contributing
Equipment to the
Fine Coal Circuit

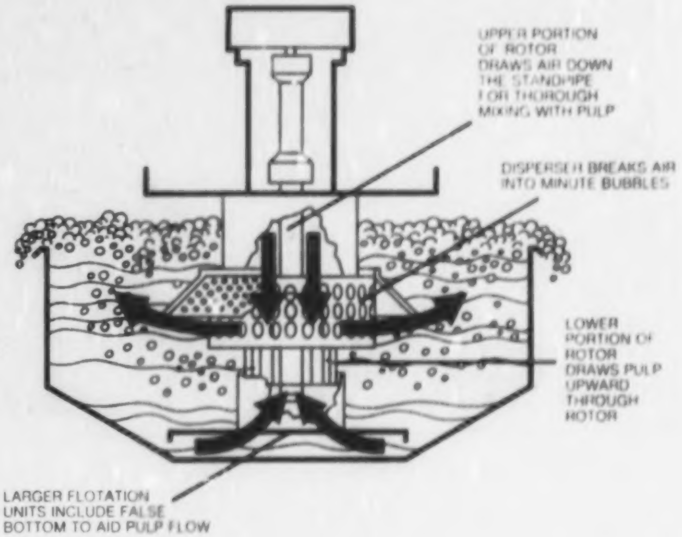
Figure 7-43 | DCN

the air bubbles to the coal particles causes the coal to be buoyed up through the rather turbulent and foamy slurry to the top where they can be removed (usually with wooden paddles) as a concentrate while the wetted refuse particles remain with the underflow and are removed to a settling system. One type of froth flotation cell is depicted in Figure 7-44. Figure 7-45 depicts the foamy coal-laden "froth" at the top of a typical flotation cell and Figure 7-46 depicts a typical multi-cell froth flotation installation.

Froth flotation cells are upright trough type steel tanks which have a central agitating device to create the air bubbles. The fine coal slurry, usually from 4 to 12 percent solids, enters at one end in conjunction with a frother reagent of one kind or another. The treated slurry flows through several adjoining cells and the frother coal (coal that is buoyed up) is decanted from the surface at about 25% solids. The tailings or underflow continue to migrate to the far end of the multi-cell where they are removed with the bulk of the water to some type of a recovery system (usually a static thickener). The concentrated coal solids are usually fed to a vacuum filter for final recovery and subsequent dewatering.

The major factors affecting the flotation of coal within the froth flotation process are:

- particle size,
- oxidation and rank of the coal,
- pulp density,
- pH and water characteristics,
- flotation reagents and
- equipment



THE FLOTATION CONCEPT

Flotation selectively separates different minerals by agitation, dispersion and gas induction. An intimate mixture of air and mineral-laden liquid is produced by dissemination of air throughout the liquid. Chemical reagents are added which selectively form a water-repellant coating on the mineral particles to be floated. Millions of tiny bubbles are created by the air/liquid mixture. The coated mineral particles adhere to the bubbles and are carried to the surface where they are removed by simple displacement. Frothing reagents increase bubble surface tension, forming a firm mineral laden froth at the pulp surface. Minerals which are not to be floated are wetted and so remain in the pulp. Either the floated or the depressed minerals may be the valuable portion.

Flotation is produced in one of two ways. Many mechanical-pneumatic flotation machines use external compressors to blow air through the cells. This produces a turbulent froth of relatively large bubbles. WEMCO aeration is induced by a rotor that entrains air in its vortex. This reduces turbulence to a minimal level while providing maximum dispersion of small bubbles.

Source: WEMCO

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The Flotation
Concept

Figure 7-44 DCN

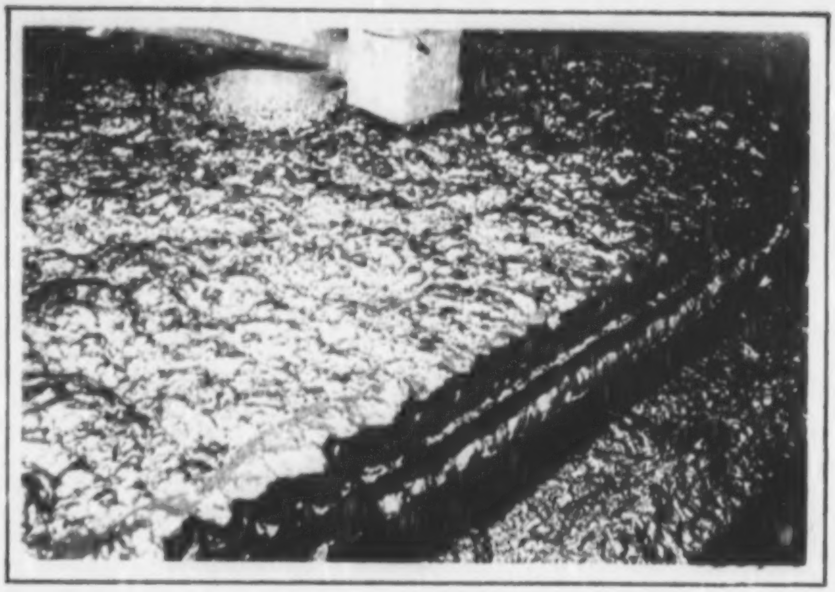

Figure 7-45
Coal Laden Froth

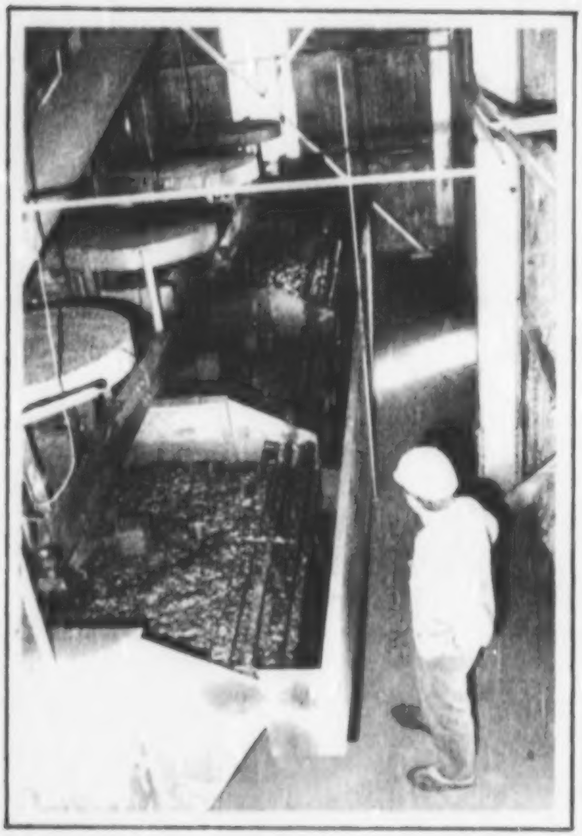

Figure 7-46
Typical Multi-Cell
Froth Flotation Installatior

Particle size is important from both mechanical and economic considerations. As noted, the intermediate size coal cleaning equipment can usually do a respectable cleaning job down to 48-mesh. As a general rule, it is more economical to clean coal by the standard specific gravity method (Deister tables or dense media cyclones) than by froth flotation, down to the minimum sizes these devices can efficiently handle. Consequently, even though particles as coarse as 3/16 inch may be floated by froth flotation, it is generally considered uneconomical. From the mechanical side, the coarse sizes are more difficult to handle due to the increased flotation rate (it takes longer retention time in the flotation unit for the coarse particles to be buoyed to the surface). The very fine size coal, say below 150-mesh, is more difficult to float than the 48 to 150-mesh, but to a lesser extent than those exceeding 48-mesh in size. Figure 7-47 highlights the floatability of coal based on particle size.

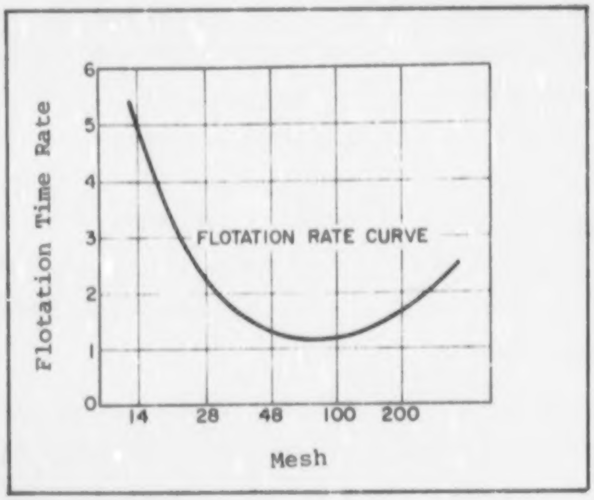

Figure 7-47
Floatability as a Function
of Particle Size

The rank and oxidation of the coal entering the flotation cells affects their floatability. Generally, low volatile coals are easier to float than most high volatile coals. Lignite is the least floatable form of coal. On the other hand, a highly floatable coal will become difficult to float if it has become highly oxidized.

The percent of solids in the coal-water slurry (pulp density) also affects the froth flotation. Pulp densities may be found between 3 and 20 percent, with an approximate average of 7 percent. The large variance in pulp density is due to treating slurries with varying particle sizes. As a general rule, the coarser the coal particles, the higher the pulp density, and the finer the coal particles, the lower the pulp density.

Both the recovery efficiency and the quality of the froth product are directly affected by the quality of the water in the coal-water slurry. Coal recovery is the highest when the pH of the water is between 6 and 7.5. The ash content in the float coal increases as the pH value increases; however, the higher the pH value the lower the percentage of pyrite in the float coal. The amount of soluble salts in the water affects flotation results, but little is known of their effect. Colloidal clays or slimes in the water inhibit the flotation process. The clays or slimes may be controlled by the proper use of chemical agents in the flotation cells or by removing them ahead of the flotation step.

The importance of using the proper amount and kind of reagents is extremely critical to the flotation process. There are three general classes of reagents: frothers, collectors or promoters and modifying agents. The main purpose of frothers (frothing agents) is to facilitate the production of a stable froth, i.e., they must create a froth that will sustain itself long enough to buoy up the coal particles and hold them on the surface until they can be removed. The only substances which can be frothers are ones which can change the surface tension of the water. Examples of frothers are amyl and butyl alcohols, terpinol and cresols. Kerosene, crude oil and various coal tars are occasionally used, however, the choice of any frother depends upon its availability, price and effectiveness on the particular coal being treated.

The function of the collector or promoter reagent is to promote contact between the coal particles and the air bubbles by forming a thin coating over the particles rendering them water repellent. The collector must be selective, that is, it must coat only the coal particles; it must not coat the refuse particles. Most of the collectors used in the flotation of coal are both frothers and collectors. Examples are MIBC (methyl isobutyl carbinol) and kerosene. For most coals, a combination frother-collector is generally all that is needed, including oxidized or low rank coals.

The largest number of reagents used in the froth flotation process are generally grouped under the heading of modifying reagents. Most reagents of the category may have several functions or varying functions under varying conditions:

- Depressing agents--are used to inhibit the flotation of unwanted particles by coating them so they will not attach themselves to the rising air bubbles. Sodium and potassium cyanides are effective depressants of zinc and iron sulfide (pyrite) minerals.

- Activating agents--are substances which so alter the surface of a mineral that it may be filmed by a collector or frother collector allowing it to more readily attach itself to the rising air bubbles.

- pH regulators--are used to govern the degree of alkalinity or acidity of the flotation slurry.
- Dispersing agents--are used to remove the slimes or clays by acting as a flocculant, and thus aiding in their settling within the flotation cell.

As noted earlier, the removal of ash and pyrite from the coal-water slurry presents a dichotomy: as removal of ash increases, the percent of pyrite in the clean coal also increases. With the increased emphasis upon pyrite removal and the continuing requirements for a low ash coal, the U.S. Bureau of Mines has developed under direction of A. W. Deurbrouck, and patented, a unique two-stage froth flotation process to remove the pyritic sulfur.

The process consists of a first stage, standard coal flotation step, in which high ash refuse and coarse or shale associated pyritic sulfur are removed as tailings. The first stage coal froth concentrate is then repulped in fresh water, pH is maintained below 7, and a coal depressant, a pyrite collector and a frother are added in a second stage to float any of the pyritic material carried over into the first stage froth; the second stage underflow is left as a final clean coal product.

Laboratory and pilot plant flotation tests with coals from various coal beds throughout the Appalachian region showed that pyritic sulfur reduction of up to 80% could be achieved by using this technique.

REFERENCES AND/OR ADDITIONAL READING

Akopov, M.G.; Cherevko, I.E.; Kinareevskiy, V.A.; Miller, E.V., "Investigations in the Area of Counterflow Coal Separation", U.S.S.R. Australian Coal Conference

Allis-Chalmers, "Screening Machinery", Engineering Bulletin on Selection of Vibrating Screens

Antipenko, L.A.; Nazarenko, V.M.; Tishchenko, A.G.; Vlasova, N.S., "Development of Coal Flotation Techniques and Technology", U.S.S.R., Australian Coal Conference

Bituminous Coal Research, Inc., "An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal", BCR Report L-339, September 1969, BCR Report L-362, February 1970, BCR Report L-404, April 1971, BCR Report L-464, April 1972

Black Sivalls & Bryson, Inc., "Study of Sulfur Recovery from Coal Refuse", U.S. Government Printing Office, September 1971

Blankenship Jack B., "New Materials for Slidability Plus Longer Wear", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Blankenship, R.E., "Operational and Environmental Features of Virginia Pocahontas No. 3 Preparation Plant", Mining Congress Journal, April 1973

Burdon, R.G.; Booth, R.W.; Mishra, S.K., "Factors Influencing the Selection of Processes for the Beneficiation of Fine Coal", Austrailia, Australian Coal Conference

Capes, C.E.; McIlhinney, A.E.; McKeever, R.E.; Messer, L., "Application of Spherical Agglomeration to Coal Preparation", Australian Coal Conference

Charmbury, H.B., "Mineral Preparation Notebook", Pennsylvania State University

Coal Age, "Coal Preparation and Unit-Train Loading", July 1972

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Coal Age, "Consol Preparation Confirms Coal Quality", October 1972

Coal Age, "Multi-Stream Coal Cleaning System Promises Help With Sulfur Problem", January 1976

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Coal Age, "Peabody Pioneers in Coal Handling & Preparation", Model Mining Issue, October 1971

Coal Age, "U.S. Steel Coal Preparation", Model Mining Issue, October 1973

Cook, L., "Practical Application of Hydraulic Mining at Rahui Buller Coalfield", Paper 31, Mining Conference, School of Mines & Metallurgy, University of Otago, May 1953

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Dahlstrom, D.A.; Silverblatt, Charles, "Production of Low Moisture Content Fine Coal Without Thermal Drying", Mining Congress Journal, December 1973

Daub, Charles H., "The Oneida Plant", Mining Congress Journal, July 1974

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

Dell, C.C.; Jenkins, B.W., "The Leeds Flotation Column", United Kingdom Australian Coal Conference

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Deurbrouck, A.W.; Palowitch, E.R., "Performance Characteristics of Coal Washing Equipment, Concentrating Tables", U.S. Bureau of Mines Report of Investigations #6239, 1965

Deurbrouck, A..; Hudy, J. JR., "Performance Characteristics of Coal-Washing Equipment, Dense - Medium Cyclones", U.S. Bureau of Mines Report of Investigations #7673, 1972

Deurbrouck, A.W., "Performance Characteristics of Coal-Washing Equipment, Hydrocyclones", U.S. Bureau of Mines Report of Investigations #7891, 1974

Deurbrouck, A.W.; Hudy, John, Jr., "Performance Characteristics of Coal-Washing Equipment, Sand Cones , U.S. Bureau of Mines Report of Investigations #6606, 1963

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Deurbrouck, A.W., Steam as a Coal Dewatering Aid During Vacuum Filtration: A Pilot Plant Study", U.S. Department of Interior, Bureau of Mines Report of Investigations #6718, 1966

Deurbrouck, A.W., "Survey of Sulfur Reduction in Appalachian Region Coals by Stage Crushing", U.S. Bureau of Mines Report of Investigations #8282

Deurbrouck, A.W., "Washing Fine-Size Coal in a Dense-Medium Cyclone", U.S. Bureau of Mines Report of Investigations #7982, 1974

Kokunin, A.V.; Onika, D.G., "Hydraulic Underground Mining", Translated for Branch of Bituminous Coal Research, Division of Bituminous Coal, U.S. Bureau of Mines

Ellison, William; Heden, Stanley D.; Kominek, Edward G., "System Reliability and Environmental Impact of SO_2 Processes", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky October 1974

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Foreman, William El; Lucas, J. Richard, "Current Status of Hydro-Cyclone Technology", Mining Congress Journal, December 1972

Foreman, William E., "Impact of Higher Ecological Costs and Benefits on Surface Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Geer, M.R.; Yancey, H.F., "Evaluation of Washery Performance", U.S. Bureau of Mines Report of Investigations #8093, 1962

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

Gospodarka, Gornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Grimm, Bobby M., "Preparation Plant Corrosion Cost", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Gvozdek, G.; Macura, L., "Hydraulic Mining in Some Deep Pits in Czechoslovakia", Translated by National Coal Board (A 1683), Uhli #12, December 1958

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Hake, W.D., "Application and Performance of Batac Jig Processing Fine Coal at Old Ben Mine 26, Sesser, Illinois", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Hall, A.W.; Martin, J.W.; Stewart, R.F.; Poston, A.M., "Precision Tests of Neutron Sulfur Meter in Coal Preparation Plants", U.S. Bureau of Mines Report of Investigations #8038, 1975

Henderson, G.S.; Andren, A.W.; Harris, W.F.; Reichle, D.E.; Shugart, H.H.; Van Hook, R.I., "Environmental Assessment of SO_2 and Trace Element Emissions from Coal Utilization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Hudy, J., Jr., "Performance Characteristics of Coal-Washing Equipment", U.S. Bureau of Mines Report of Investigations #7154, July 1968

Hulett, L.D.; Carter, J.A.; Cook, K.D.; Emery, J.F.; Klein, D.H.; Lyon, W.S.; Nyssen, G.A.; Fulkerson, W.; Bolton, N.E., "Trace Element Measurements at the Coal-Fired Allen Steam Plant--Particle Characterization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky 1974

Humboldt-Wedag, "Manufacturers Brochures", Cologne, Germany

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Provence Coalfield", France, Australian Coal Conference

Irminger, P.F.; Giberti, R.A., "Desulfurization Technology to Meet the Power Demand", NCA/BCR Coal Conference and Expo II, October 1975

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracite in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jeffrey Mining Machine Co., "Jeffrey Mining Machine Company: Manufacturers Information", Columbus, Ohio

Jenkinson, D.C., "Some New Coal Preparation Developments in the United Kingdom", National Coal Board Bulletin M4-B148

Johnson Division, UOP Company, "Brochure - 1975"

Johakin, J., "Solving the SO_2 Problem--Where We Stand with Application and Costs", Coal Age, May 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Kent, James A. (Editor), "Riegel's Handbook of Industrial Enchistry (7th Ed.)", Van Nostrand Reinhild Publishing Company, New York, 1974

Kester, W.M., "Magnetic Demineralization of Pulverized Coal"

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

Kollodiy, K.K.; Borodulin, V.A.; Nazarov, P.G., "Processing of Coal Mined by the Hydraulic Method", Ugol #9, 1974 (Translated by Terraspace)

Korol, Dionizy, "Influence of Hydraulic Getting on Mechanical Coal Preparation", Przeglad Gorniczy, Year 12 #12, December 1956 (National Coal Board Translation Section)

Kuti, Joe, "Longwall vs. Shortwall Systems", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Lamella, (Sala of Sweden), "Theory and Design of the Lamella Gravity Settler", Technical Bulletin #105, May 1975

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Llewellyn, Robert L., "Coal Preparation", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York, 1968

Lotz, Charles W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Lowman, Stephen G., "Westmoreland Coal's Bullitt Plant Upgrades Steam Coal Quality", Coal Age 1973

Lowry, H.H. (Editor), "Chemistry of Coal Utilization", John Wiley & Sons, Inc., New York, New York, 1963

Lovell, Harold L., "Sulfur Reduction Technologies in Coals by Mechanical Beneficiation (3d Draft)", Commerce Technical Advisory Board Panel on SO_2 Control Technologies, March 1975

Manwaring, L.G., "Coarse Coal Cleaning at Monterey No. 1 Preparation Plant", Mining Congress Journal, March 1972

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Markley, R.W.; Cavallaro, J.A., "Efficiency in Cleaning Fine Coal by Froth Flotation--A Cell by Cell Pilot Plant Evaluation", Mining Congress Journal, June 1974

Mathur, S.P., "Hydraulic Mining of Coal", Journal of Mines, Metals and Fuels, May 1972

McNally-Pittsburg Manufacturing Corporation, "Coal Cleaning Plant Prototype Plant Design Drawings", Department of Health, Education and Welfare Contract 22-68-59

McNally-Pittsburg Manufacturing Corporation, "Coal Preparation Manual 572", Extensive Analysis on McNally Pittsburg Coal Cleaning Technology

Mengelers, J.; Absil, J.H., "Cleaning Coal to Zero in Heavy Medium Cyclones", Coal Mining and Processing, May 1976

Miller, Kenneth J., "Coal-Pyrite Flotation: A Modified Technique Using Concentrated Second-Stage Pulp", U.S. Bureau of Mines Coal Preparation Program, Technical Progress Report 91, May 1975

Miller, K.J.; Baker, A.F., "Flotation of Pyrite from Coal", U.S. Bureau of Mines Technical Progress Report #51, February 1972

National Coal Board, "Hydraulic Transport of Coal at Woodend Colliery", September 1961

Nirtsiyev,"Hydraulic Extraction of Coal in the Donetz Basin Izdatel 'Stvo "NEDRA", Moscow 1969 (Translated by Terraspace)

Norton, Gerry; Bluck, Willard V., "A High Intensity Fine Coal Flotation Cell", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Nunenkamp, David C., "Survey of Coal Preparation Techniques for Hydraulically Mined Coal", Published for Terraspace Inc., July 1976

O'Brien, Ellis J.; Sharpeta, Kenneth J., "Water-Only Cyclones; Their Functions and Performance", Coal Age, January 1976

Parkes, David M; Grimley, A.W.T., "Hydraulic Mining of Coal", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Poland, "Beneficiation of Coal Fines by Selective Flocculation", Australian Coal Conference

Protopapas, Panayotis, "A Report in Mineral Processing", Department of Applied Earth Sciences, Stanford University, 1973

Protsenko, I.A., "The Technology of Beneficiation and Dewatering of Coal Mined by the Hydraulic Method", Questions Regarding the Hydraulic Production of Coal, Trudy VNIIGidrougol, Vol. XI, 1967 (Translated by Terraspace)

R.M. Wilson Company, Inc., "Mine Productivity Systems and Equipment", Catalog #288-P

Roberts & Shaefer Company, "Manufacturers Information Booklets", Chicago, Illinois

Roberts & Schaefer Company, "Design & Cost Analysis Study for Prototype Coal Cleaning Plant", August 1969

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant", January 1973

Sal'Nikov, V.R., "Experience and Outlook Regarding the Application of Hydromechanization of Steep Seams in the Kuzbass", UGOL #7, 1973

Sands, P.F.; Sokaski, M.; Geer, M.R., "Performance of the Hydrocyclone As a Fine Coal Cleaner", U.S. Bureau of Mines Report of Investigations #7067, January 1968

Sarkar, G.G.; Konar, B.B.; Sakha, S.; Sijha, A.K., "Demineralization of Coal by Oil-Agglomeration", Part I: Studies on the Applicability of the Oil-Agglomeration Technique to Various Coal Beneficiation Problems, India, Australian Coal Conference

Schuhmann, Reinhardt, Jr., "Metallurgical Engineering, Vol. I, Engineering Principle", Addison-Westey Publishing Company, Inc., Reading, Massachusetts, 1952, p.84

Skinderowicz, F., "Typical Technical Solutions of a Loading Point During Gravity Hydraulic Transportation of Coal", Wiadomosci Gornicza, Vol. 10 #3, 1959

Sokaski, M.; Jacobsen, P.S.; Geer, M.R., "Performance of Baum Jigs in Treating Rocky Mountain Goals", U.S. Bureau of Mines Report of Investigations #6306

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Sokaski, M.; Sands, P.F.; Geer, M.R., "Use of a Sieve Bend and a Scalping Deck With a Vibrating Screen in Dewatering and Draining Dense Medium From Fine Coal", U.S. Bureau of Mines Report of Investigations #6311

Stefanko, Robert; Ramani, R.V.; Chopra, Ish Kumar, "The Influence of Mining Techniques on Size Consist and Washability Characteristics of Coal", National Technical Information Service, Springfield, Virginia, August 1973

Stoev, St.; Krasteva, K., "Coal Preparation by Reverse Stratification", Bulgaria, Australian Coal Conference

Sztaba, K; Tajchman, Z., "Regression Model of Coal Flotation Process", Poland, Australian Coal Conference

Tieman, John W., "Chemistry of Coal", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York 1968

Tompos, E., "Detailed Investigation of Pyrites Distribution, Taking Account of the Petrographic Components of Coal, with a View to Reducing the Pyrites Content in Coking Coal", Hungary, Australian Coal Conference

Tyler, C.D., "Testing Sieves & Their Uses", Combustion Engineering, Inc. Handbook #53, 1973 Edition

Warnke, W.E., "Latest Progress in Sulfur, Moisture and Ash Reduction Coal Preparation Technology", American Mining Congress Coal Convention, Detroit, Michigan, May 1976

Wei-Tseng Peng, "The Jet-Cyclo Flotation Cell", The People's Republic of China, Australian Coal Conference

Wemco Division, "Manufacturer's Catalog", Envirotech Corporation Sacramento, California, 1974

Yancey, J.F.; Geer, M.R., "Behavior of Clays Associated with Low-Rank Coals in Coal-Cleaning Processes", U.S. Bureau of Mines Report of Investigations #5961

Yancey, J.F., "Determination of Shapes of Particles in Coal and Their Influence on Treatment of Coal by Tables", AIME Translation, 94

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Zimmerman, R.E., "Batac Jig - A New Improved Baum Type Jig for Cleaning Coarse and Fine Sizes of Coal", American Mining Congress Coal Convention, May 5-8, 1974

8. PRODUCT DEWATERING AND DRYING

8.1 OVERVIEW

Removing water from clean coal and refuse products is a major coal preparation problem, second only to the removal of pyrite. Excessive moisture in the coal and refuse leaving the plant is an undesirable impurity for numerous reasons, i.e., the moisture:

- compounds the handling and haulage problems of the coal and refuse,
- increases the transportation costs of the clean coal and the refuse,
- reduces the effective Btu content of the clean coal,
- causes undue absorption of energy during the combustion process and
- renders the coal undesirable for coking.

Clean coal and refuse coming from a wet cleaning unit are usually accompanied by large volumes of water which must be removed as the product is sized and the heavy media removed (if media are used) prior to additional processing. Provisions for dewatering or for dewatering and drying clean coal and refuse are, therefore, a necessary part of wet cleaning plants. Drying of the ROM coal feed may also be necessary in a dry cleaning plant if the moisture content of the raw coal is not low enough to permit air tabling.

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The product dewatering and drying module is defined as all activity relating to removing water from the clean coal and refuse products. This module is highlighted in Figure 8-1.

8.2 METHODOLOGY

The removal of moisture from coarse size coal is relatively simple, while the removal of water from 10-mesh coal or finer is a major problem usually requiring an individual solution at each cleaning plant.

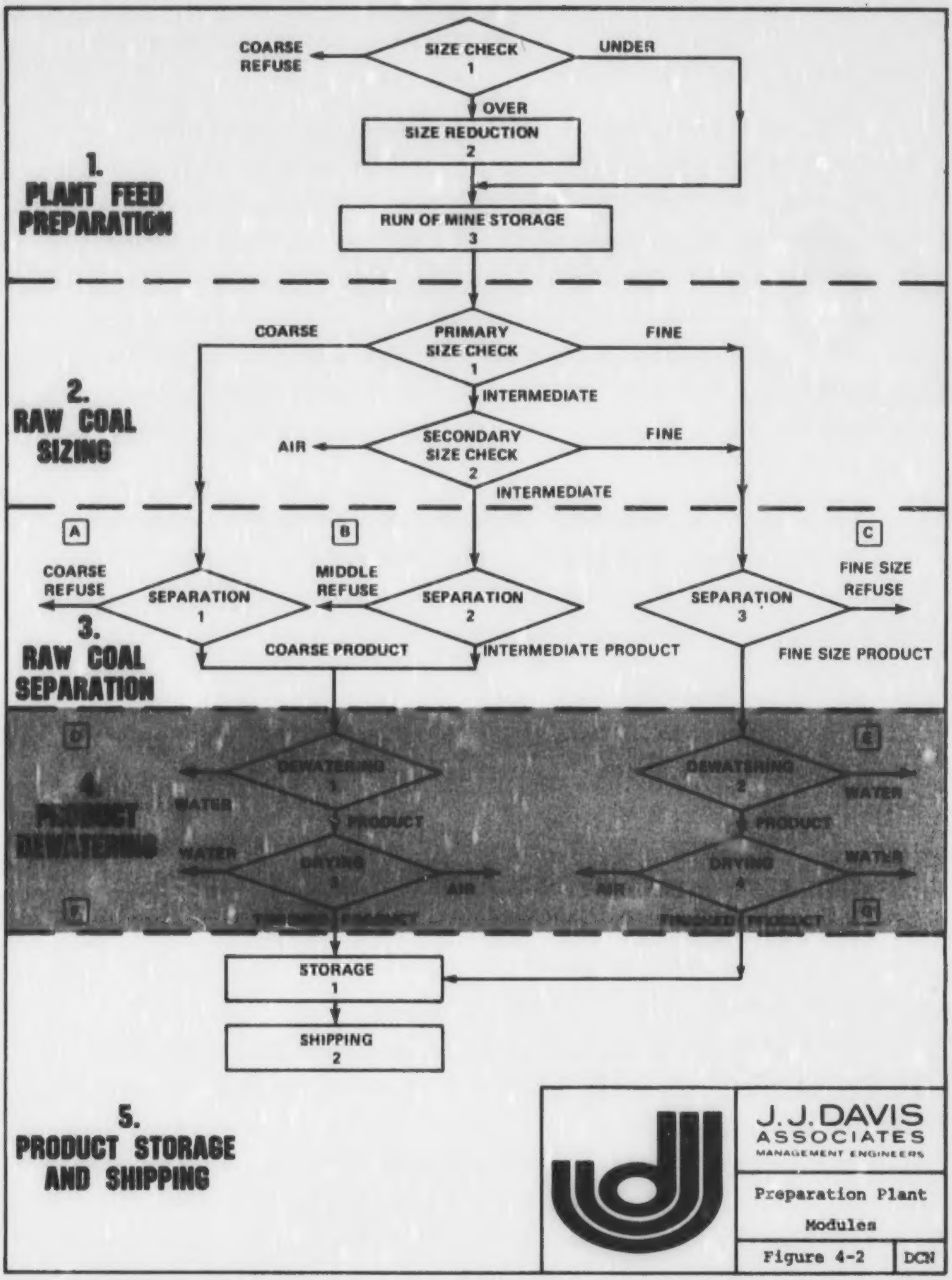
There are a number of methods that are used in the dewatering of coal and refuse and in the dewatering and drying of coal. These dewatering methods may be generally grouped into five categories:

- natural drainage,
- screening,
- centrifugal dewatering,
- thickening and filtering and
- heat drying.

In practice, considerable overlapping of applications occur among these dewatering techniques.

8.2.1 Natural Drainage

Natural drainage by the use of hoppers and bins has been practiced for years, but has been largely replaced by the sizing and dewatering shakers or vibrating screens. Today, natural drainage is usually practiced only on the coarse sizes of coal and refuse. The products are generally delivered to specifically designed bucket elevators and bins where the surface moisture is allowed to drain away (see Figure 8-2). Natural drainage is generally rapid and complete for coal coarser than ½ inch. On the other



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Preparation Plant Modules

Figure 4-2 DCN

hand, coal fines and clay particles greatly increase the necessary time for complete drainage.

Natural drainage is usually used for preliminary dewatering of the coarse refuse in the modern preparation plant and is often accomplished by utilizing drainage conveyors and bucket elevators. In most installations the conveyors are inclined, and the conveyor speed is timed to allow the natural drainage or to at least provide a high degree of dewatering prior to further dewatering by means of vibrating screens. Where vertical elevation is desired, perforated bucket elevators are usually employed (see Figure 8-2).

The natural drainage process by means of conveyors, bucket elevators and hoppers may reduce the surface moisture content of the coarse coal or refuse to 5 or 6 percent under normal operating conditions.

8.2.2 Screens

Fixed screens, shaking screens and vibrating screens are often employed for dewatering coal and refuse. Screens are a natural choice for the initial dewatering operation because of their ease of use, their ability to size the coal simultaneously, their maximum retention of the particles which insures adequate rinsing for media recovery and their relative low cost. A typical vibrating screen installation is shown in Figure 8-3.

Screens are commonly used to dewater coal and refuse of all sizes. However, when the shaking screen is used for dewatering coals smaller than 3/8 inch or ½ inch, the screen capacity decreases so rapidly that an excessive screen length is required or a number of screens must be used to dewater any considerable tonnage. The high speed shaking screens can be successfully used to dewater plus

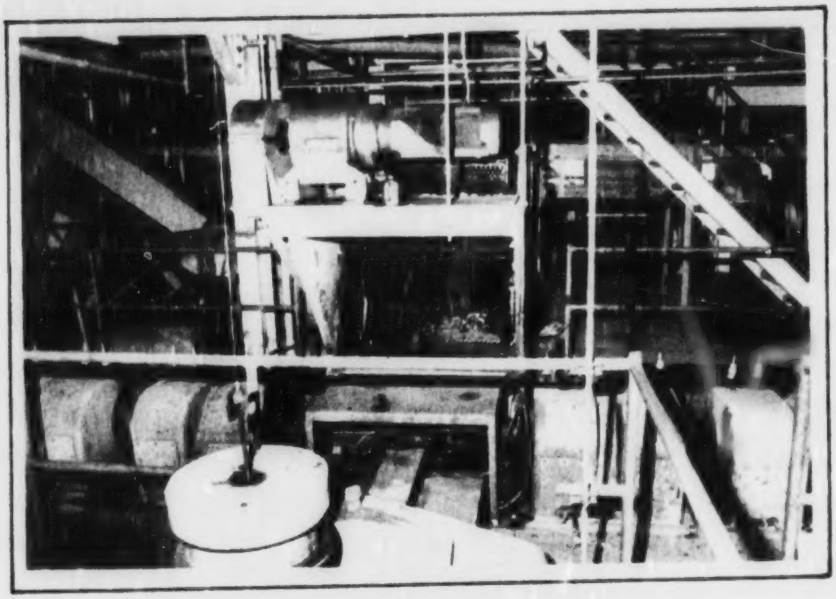


Figure 8-2
Natural Drainage via a Bucket Elevator

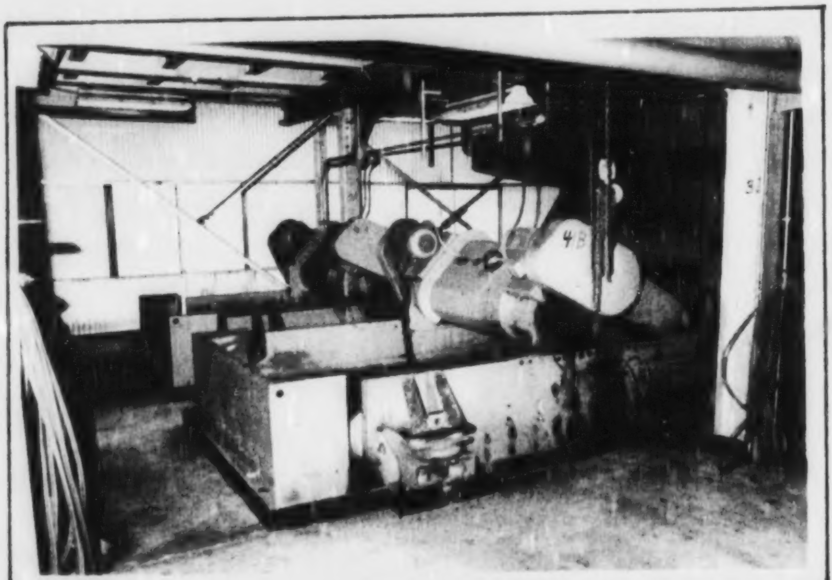


Figure 8-3
Typical Vibrating Screen Installation

3/4 inch to plus ½ inch bituminous coals to a final surface moisture of 3%. Normally, however, high speed shakers are operated so as to give a final surface moisture in the range of 5 to 10%. The minus 28-mesh material is generally removed in this process and must be further dewatered or sent to the waste dump.

The particle movement and high capacity dewatering effect of the shaking and vibrating screens are achieved by high intensity vibrations and by the continuous tumbling of the product particles on the screen surface owing to the opposition of the screening surface to their forward flow. The only difference between the vibrating screens used for sizing and the vibrating screens used for dewatering is that in the dewatering operation the screens are used at less steep angles than when used strictly for the sizing operations. In general, the vibrating screens will yield higher capacities in dewatering operations than will shaker screens because greater energy may be imparted directly to the particles through the increased amplitude available in the vibrating screen.

The vibrating and shaking screens used in dewatering coal and refuse may be selected by the use of standard screen formulas (see Chapter 7), but the surface moisture of the product requires considerable additional attention before the final selection process is completed.

As the surface moisture of the coal increases from the bone dry state, a point is reached where the coal particles begin to adhere to each other due to the surface tension of the moisture film. As this point is reached, the fine particles stick to the oversized particles and begin to ride over the screen, resulting in poor screen efficiency. As the surface moisture continues to increase, another point is reached where the damp particles wet the wire on the screen surface and binding commences. (As the wire becomes coated with a film of moisture, the fine particles adhere to them. As the process continues, the screen apertures are progressively closed off by a blanket of material until, ultimately, screening ceases.)

The residual surface moisture of coal is usually considered to be a function of the surface area of the coal, although many other factors may contribute. If we assume that the surface moisture is in direct proportion to the surface area, then the finer sizes having the greater surface area for a given weight will hold the most water. For example, the surface moisture of 1½ inch x ¼ inch coal would be lower than the surface moisture of ½ inch x 0 coal if measured in comparable environments. However, the actual surface moisture depends upon the type of coal, the size distribution of the particles, the efficiency of the preceding screening, the ash content, the tonnage handled, the retention time on the screen, the interruptions in the screen surface and whether the product is from the top or the bottom deck of the screen.

The dewatering screen selections are based on handling a bed depth of material thin enough to be free draining. The depth of the product on the screen is a function of the size of the particles being dewatered since the smaller the average particle size, the more difficult it is to drain the bed and, therefore, the thinner the bed must be. (The presence of the fine coal particles tends to fill the voids and hold the water.)

Coarse coal may be sized and dewatered on the same screen, but fine coal is not usually sized at this point since the primary purpose of the screen is to retain the salable coal solids while removing the water.

When dewatering the fine coal on screens, the openings in the screen surface are usually very small (¼ mm to ½ mm) and it is necessary to provide sufficient screen area to pass the water. Fine coal has a tendency to pack, stratify or to form a blanket or a cake. Better dewatering can be obtained if the bed is periodically disturbed. In order to mix up the bed of coal, cross dams are usually used on the screen surface. Cross dams force the coal to climb over the dam, making the bed more porous and permitting the free drainage of water. On the other hand, some operators use a water spray to break up the bed of coal or in conjunction with the cross dams.

The capacity of fine coal dewatering screens is influenced by the amount of water in the feed. If the amount of water is too great, the high entrance velocity resulting will cause the coal to flush down the deck, reducing the screen area available for dewatering. Under these conditions the surface moisture of the dewatered coal will be very high and, under extreme conditions, free water may be discharged with the coal. In order to prevent excessive surface moisture of the dewatered product, the amount of water admitted with the feed must be limited. Tables 8-1, 8-2, 8-3, 8-4 and 8-5 give the capacity of coal dewatering screens at various sizes of product and show the maximum amount of water that can be admitted with the feed. If the free water with the coal will exceed the amount indicated, a stationary sieve ahead of the screen must be used to reduce the incoming water.

8.2.2.1 Special Purpose Screens for the Heavy Media Process The heavy media process (discussed in detail in Chapter 7) is a method of cleaning coal based on the differences in specific gravity between coal and its impurities. The raw pre-wetted coal is fed to a separatory vessel

Table 8-1
TPH Capacity of Vibrating Screens
Dewatering Presized Coal at ½"

Screen Width (Ft.)	Maximum Water with Feed (GPM)	Size of Coal						
		3/4 x 1/4	1 1/4 x 1/4	2 x 1/4	3 x 1/4	4 x 1/4	5 x 1/2	6 x 1/2
3	750	60	65	75	80	90	95	100
4	1050	84	91	105	112	126	133	140
5	1350	108	117	135	148	162	171	180
6	1650	132	143	165	180	198	209	220
7	1950	156	170	195	215	234	247	260
8	2250	180	195	225	248	270	285	300

Table 8-2
TPH Capacity of Vibrating Screens
Dewatering Coarse Presized Coal at ½ mm

Screen Width (Ft.)	Maximum Water with Feed (GPM)	Size of Coal							
		7/16 x 3/32	3/4 x 1/4	1 1/4 x 1/4	1 5/8 x 9/32	2 1/4 x 1/8	2 3/4 x 5/16	3 1/2 x 1/4	4 x 1/4
3	350	45	50	55	60	65	70	75	80
4	490	63	70	77	84	91	98	105	112
5	630	81	90	99	108	117	126	135	148
6	770	99	110	121	132	143	154	165	180
7	910	117	130	143	156	170	182	195	215
8	1050	135	150	165	180	195	210	225	248

Table 8-3
TPH Capacity of Vibrating Screens
Dewatering Fine Coal at ½ mm

Screen Width (Ft.)	Maximum Water with Feed (GPM)	Size of Coal							
		1 x 0	1/2 x 0	3/8 x 0	5/16 x 0	1/4 x 0	3/16 x 0	1/8 x 0	10M x 0
3	170	35	30	27	25	22	20	15	12
4	230	49	42	38	35	32	28	21	17
5	290	63	54	50	45	40	36	27	22
6	350	77	66	60	55	49	44	33	27
7	410	91	78	71	65	58	52	39	32
8	470	105	90	82	75	67	60	45	37

Table 8-4
TPH Capacity of Vibrating Screens
Dewatering Fine Coal at ½ mm

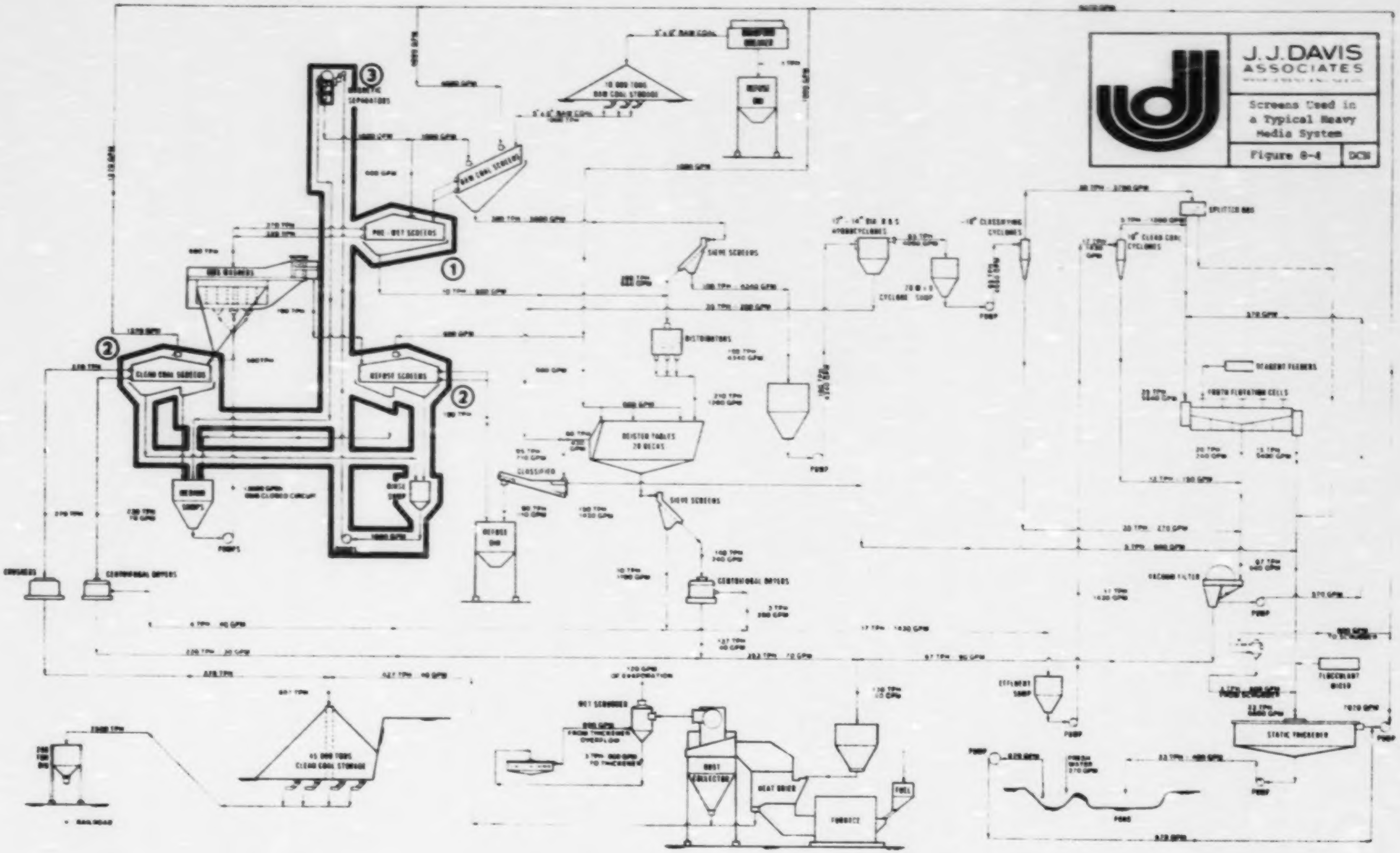
Screen Width (Ft.)	Maximum Water with Feed (GPM)	Size of Coal							
		1 x 0	½ x 0	⅜ x 0	5/16 x 0	¼ x 0	3/16 x 0	⅛ x 0	10M x 0
3	275	46	42	37	35	30	27	22	17
4	385	65	59	52	49	42	38	32	24
5	495	83	76	67	63	54	50	40	31
6	605	102	93	83	77	66	60	49	38
7	715	120	110	97	91	78	71	58	45
8	825	139	127	113	105	90	82	67	52

Table 8-5
TPH Capacity of Vibrating Screens
Dewatering Fine Coal at 1 mm

Screen Width (Ft.)	Maximum Water with Feed (GPM)	Size of Coal							
		1 x 0	½ x 0	⅜ x 0	5/16 x 0	¼ x 0	3/16 x 0	⅛ x 0	10M x 0
3	550	49	45	40	37	31	30	25	20
4	770	68	63	56	52	45	42	35	28
5	990	88	81	72	67	58	54	45	36
6	1210	107	99	86	83	72	66	55	44
7	1430	127	117	104	97	85	78	65	52
8	1650	145	135	120	113	97	90	75	60

containing a suspension of finely ground media (usually magnetite, Fe_3O_4) and water creating a synthetic specific gravity which is maintained at a point between the specific gravity of the coal and the specific gravity of the refuse. This synthetic specific gravity will allow the coal to float and will permit the refuse to sink.

To help illustrate the screens used in a heavy media system, Figure 8-4 outlines a typical installation. Ahead of the heavy media vessel, vibrating screens are used for pre-wetting the feed and removing the fines. (Refer to



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Screens Used in a Typical Heavy Media System

Figure 8-4

DCN

Figure 8-4.) (1) Pre-wetting the incoming coal controls the amount of water introduced into the heavy media vessel and assists in the maintenance of the desired specific gravity in the vessel. Removing the fine material ahead of the vessel prevents contamination of the separating media with fines. Fines have a tendency to remain in suspension which adversely affects the specific gravity.

Following the heavy media vessel, the sink, float and middling products (if recovered) are handled separately to remove the water and to recover the media riding on the product particles. A media recovery screen (2) drains the media, washes and then dewaters the coal, middlings or refuse. In order to perform these three operations, 16 foot or longer screens are usually selected, although in some installations two shorter screens are used in tandem. The drain section is usually the first 4 to 6 feet at the feed end of the screen and the media drained off at this point may be returned directly to the vessel since it is of full strength. Following the drain section, the product is washed using spray water and the media recovered is concentrated before being returned to the heavy media system. (3) Approximately 4 to 6 feet of screen length is used for washing with 1½ to 3 GPM of spray water used per ton of coal. The remaining length of the screen is used for dewatering the product.

Media recovery screens are selected on the basis of the bed depth that can be successfully drained and rinsed. Table 8-6 shows the capacity of typical media recovery screens. The tonnages indicated are maximum feed rates for average media recovery. The values shown in Table 8-6 should be increased by approximately 30% if the media recovery screen is used for refuse because of the reduced volume of material per weight (water) and because the refuse tends to drain more quickly.

Table 8-6
TPH Capacity of Single Deck Low-Head Media
Recovery Screens at ½ mm

Size of Screen (Ft.)	Feed Size									
	3/8" x 1/2 mm	7/16" x 10 Mesh	3/4" x 1/4"	1" x 1/4"	1 1/4" x 1/4"	2" x 1/4"	3" x 1/4"	4" x 1/4"	5" x 1/2"	6" x 1/2"
3 x 16	16	25	32	34	36	43	52	60	80	85
4 x 16	22	35	44	48	51	60	73	85	110	118
5 x 16	28	45	57	61	65	78	94	110	140	151
6 x 16	35	55	70	75	80	94	115	135	170	185
7 x 16	42	65	83	89	95	112	136	170	200	218
8 x 16	48	75	95	102	110	130	157	210	230	250

8.2.2.2 Special Purpose Combination Screens (Intermediate and Fine Size Coal Circuit) In some cases, special combination sizing, dewatering and desliming screens may receive the fine coal feed coming from concentrating (Deister) tables. These screens are usually of the double deck variety with the top deck arranged to make a separation at 10-mesh, 1/8 inch, 5/32 inch or 3/16 inch round. The oversize from the top deck is usually set at ½ mm separation size and the over product is routed to a centrifuge prior to going to the heat dryer. The undersize from the bottom deck is thickened, filtered and recovered or disposed of in a settling pond.

Horizontal 16 foot screens are usually selected for this application. Either deck may be the limiting deck (capacity) depending upon the separation and the analysis of the feed. Table 8-7 gives the capacities of typical screens for various operating conditions. At least one row of sprays is recommended for the top deck to break up the cake, and at least three rows on the bottom deck. Blinding and flooding of the bottom deck are typical in this application and the screens must be watched carefully.)

Table 8-7
TPH Capacity of Combination Sizing, Dewatering and Desliming Screens Handling 3/8 x 0 or 1/4 x 0 Coal

Size of Screen (Ft.)	Top Deck				Bottom Deck			
	Screen Cloth Opening			Approx.② Surface Moisture (%)	Feed			Approx.② Surface Moisture (%)
	.10 x $2\frac{5}{16}$ ①	.125 x $2\frac{5}{16}$	.1875 x $3\frac{5}{16}$		.10 x 0	$\frac{1}{4}$ x 0	$\frac{5}{16}$ x 0	
	③	③	③					
3 x 16	37	41	56	11-17	19	21	24	26-32
4 x 16	52	57	78	11-17	26	30	33	26-32
5 x 16	67	73	100	11-17	34	38	43	26-32
6 x 16	82	90	123	11-17	41	47	52	26-32
7 x 16	97	106	145	11-17	48	55	62	26-32
8 x 16	110	122	165	11-17	56	64	71	26-32

(1) Called 10 mesh by some operators.

(2) Surface moistures depend upon the analysis of the overproduct from the deck and the type of coal. Surface moisture will decrease as the top size of the overproduct is increased.

(3) Indicated capacity is only approximate. Use screen formula for wet screening to determine area required. Bed depth may be the limiting factor.

8.2.2.3 Special Purpose Solid Recovery Screens All wet process preparation plants use large quantities of water which are eventually reused or discarded. This water contains fine coal or refuse solids which must be removed if the water is to be reused or discarded. In the past, coal operators used settling ponds or abandoned mines to settle the fine coal solids and then either reused the water or discharged it into streams. Modern practice in closed circuit preparation plants is to install machinery for collecting the solids from the plant slurry and reusing the water. The equipment used to clarify the slurry normally consists of rakes, spiral or bowl classifiers, drag tanks, settling cones, centrifuges, cyclones and filters. A special purpose vibrating screen may be used as an auxiliary to these solids-recovery units. The screen (when used) usually follows the thickening unit and precedes the centrifuge or filtering units. Under certain conditions, solids-recovery screens are used alone and the underflow from the screen is sufficiently clarified for reuse in the plant.

Most coals are excellent filtering agents, and this phenomenon is used in recovering solids on a vibrating screen. In order to form a deep filtering bed on a solids-recovery screen, it is necessary to use cross dams or to run the screen uphill. Figures 8-5 and 8-6 depict typical solids-recovery screen applications. The thick layer of coal created on the screen deck acts as its own filter by trapping further solids introduced with the feed. Solids-recovery screens usually have openings of ¼ mm, or the first section with ½ mm and the balance with ¼ mm openings. These screens have heavier deck construction than standard screens because of the increased load of coal and water carried on the deck.

Solids-recovery screens can be operated by either forming a bed with ¼ inch x 0 coal or refuse and then depositing the slurry on the bed 6 to 8 feet down the screen or by using the slurry to form the bed and then recirculating the fines and water that initially pass through the screen as the second layer on the previously formed bed. In the latter case, the slurry is usually sent to a secondary cyclone for thickening before it is returned to the screen. In order to form a filter bed, 15 to 20% of the solids in the slurry must be larger than the screen openings and the feed should contain 40 to 60% solids. Refuse is used as a filter bed if the solids recovered contain high ash and are to be discarded as refuse. Tables 8-8 and 8-9 show capacities of typical solids recovery screens.

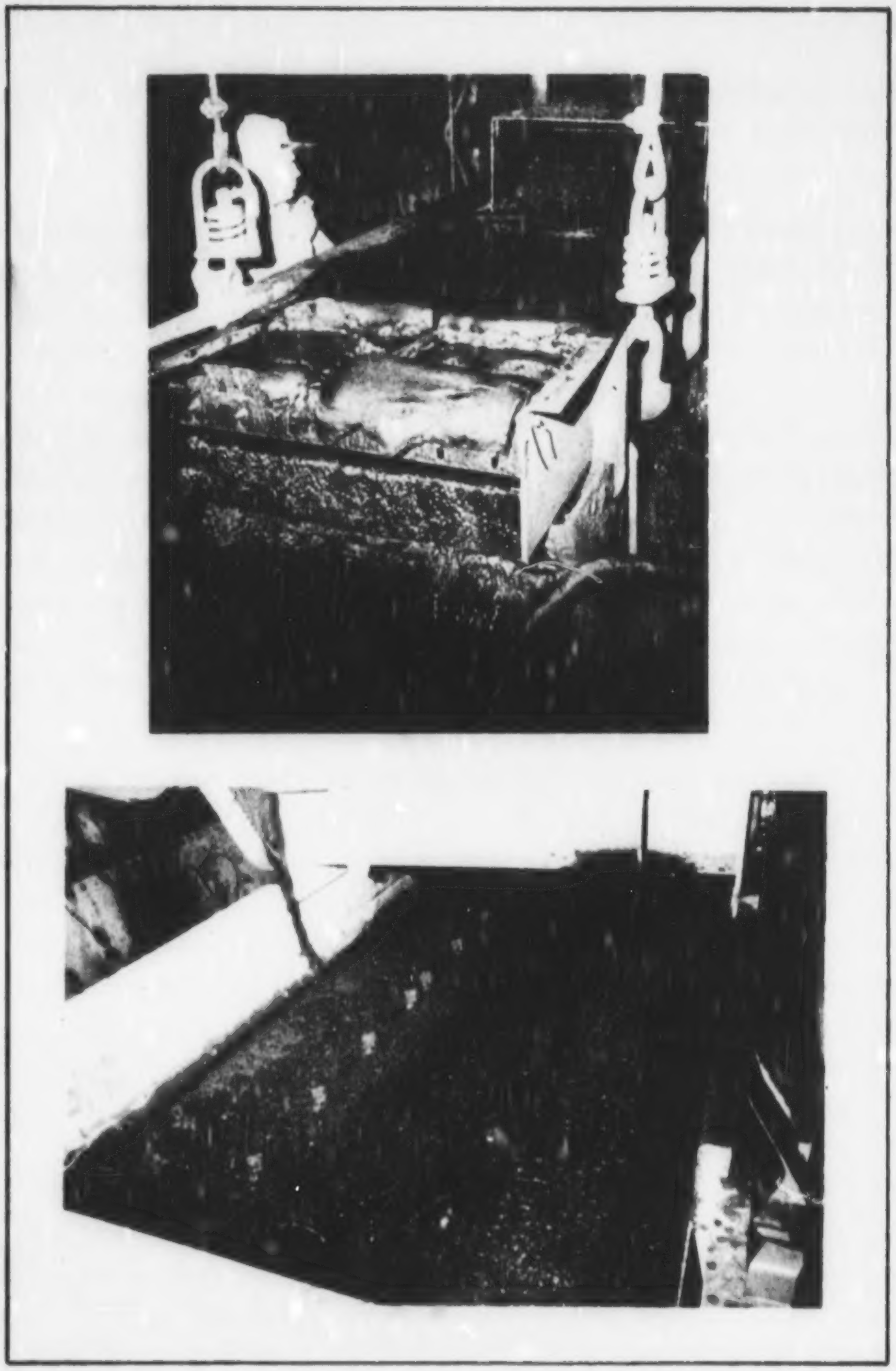
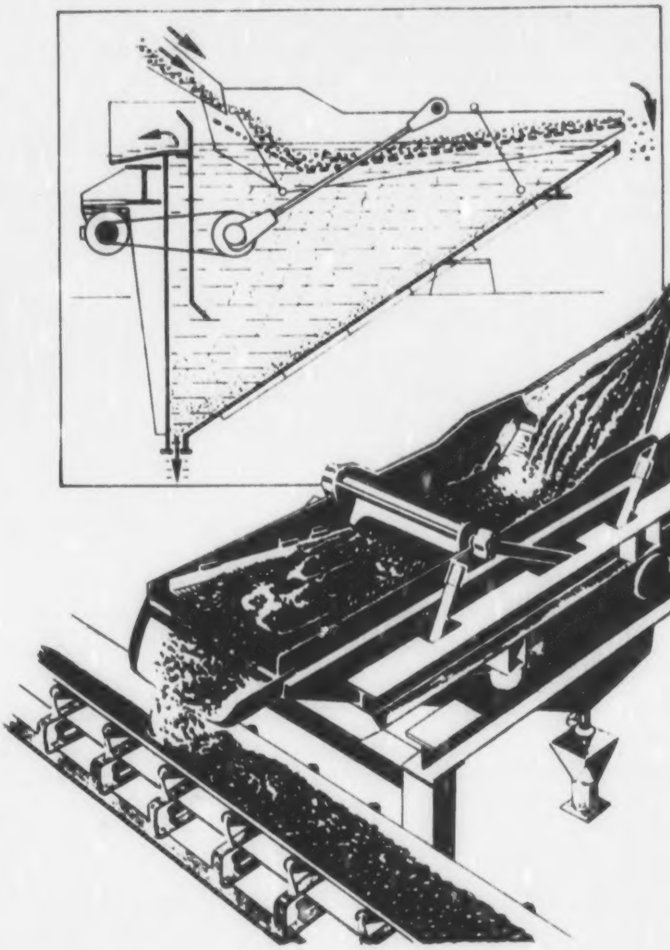


Figure 8-5

Solid Recovery Screen Applications



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RUNNING THE
SCREEN PRODUCT
UPHILL

Figure 8-6. DCN

Table 8-8

TPH Capacity of Solids Recovery Screens Receiving Only Fine Coal Feed 1 mm or ½ mm x 0

Size of Screen (Ft.)	Openings in Screen Surface (MM.)	Max. TPH of 1 mm. x 0 Feed	Max. TPH of Secondary Cyclone Underflow to Top Bed	Estimated Surface Moisture of Cake
3 x 16	¼	8	½ to 1	22 to 28
4 x 16	¼	12	1 to 1½	22 to 28
5 x 16	¼	16	1½ to 2	22 to 28
6 x 16	¼	20	2 to 2½	22 to 28
7 x 16	¼	24	2½ to 3	22 to 28
8 x 16	¼	28	3 to 3½	22 to 28

Table 8-9

TPH Capacity of Solid Recovery Screens Receiving ¼" x 0 Coal and Thickened Fine Coal Slurry

Size of Screen (Ft.)	Openings in Screen Surface (MM.)	Max. TPH ¼" x 0 Feed	Max. GPM Water with Feed	Max. TPH of Cyclone Underflow	Estimated Surface Moisture of Cake
3 x 16	¼	12	150	3½	20 to 25
3 x 16	4' – ½ feed end followed by ¼	13	200	3½	18 to 23
4 x 16	¼	16	200	4½	20 to 25
4 x 16	4' – ½ feed end followed by ¼	19	250	4½	18 to 23
5 x 16	¼	21	250	6	20 to 25
5 x 16	4' – ½ feed end followed by ¼	24	300	6	18 to 23
6 x 16	¼	25	300	7½	20 to 25
6 x 16	4' – ½ feed end followed by ¼	30	350	7½	18 to 23
7 x 16	¼	30	350	8½	20 to 25
7 x 16	4' – ½ feed end followed by ¼	35	400	8½	18 to 23
8 x 16	¼	35	400	10	20 to 25
8 x 16	4' – ½ feed end followed by ¼	40	450	10	18 to 23

8.2.2.4 Special Purpose Fixed Screens Screens, particularly those used for fine sizing, dewatering and recovery of dense media, comprise a significant part of the cost of coal preparation plants. Their capacity is low (as indicated in Tables 8-1 through 8-9) in relation to their floor space requirement. In addition to their initial cost, screens add proportionately to the building cost. The use of screens is increasing because of the increased proportion of the fines in the washery feed and the present trend toward recovering the finest sizes of coal. Thus, any improvement in the capacity of screens contributes substantial reductions in plant capital costs as well as increasing the throughput capacity of the plant.

The sieve bend is a curved stationary sieve developed by the Dutch State Mines. Figure 8-7 depicts a typical DSM sieve bend. The patented design of these units evolved from development work initiated in the Netherlands during the early 1950's. The screens were first used in dewatering and coarse sizing applications. Today, the sieve bend is usually placed ahead of the vibrating screen in order to reduce the water load on the screen, although occasionally it is used as the only sizing and dewatering device for certain operations.

The sieve bend is a truly fixed screen having no vibrating or moving parts. The sieve bend operates without power if it is positioned at a lower elevation than its source feed. The fluid action of the feed and the force of gravity combined with the centrifugal force developed from its curvilinear shape aid in its operation (see Figure 8-8).

The sieve bend is usually made of Bixby-Zimmer or Wedgewire screen surface with the openings in the surface at right angles to the flow of the feed down the screen.

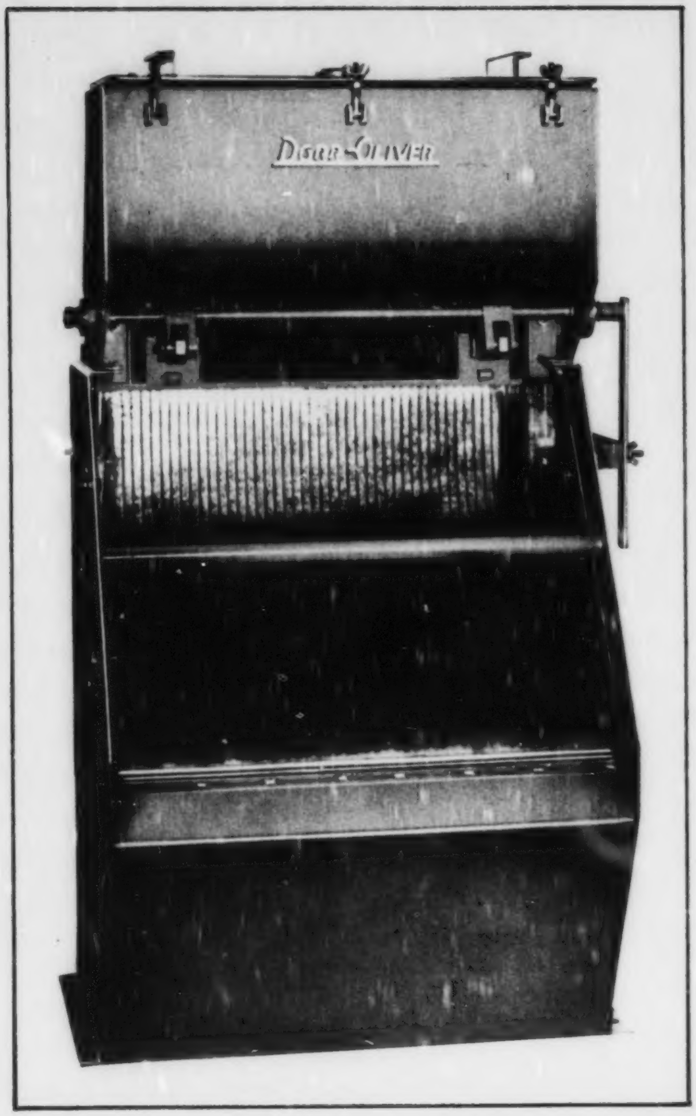
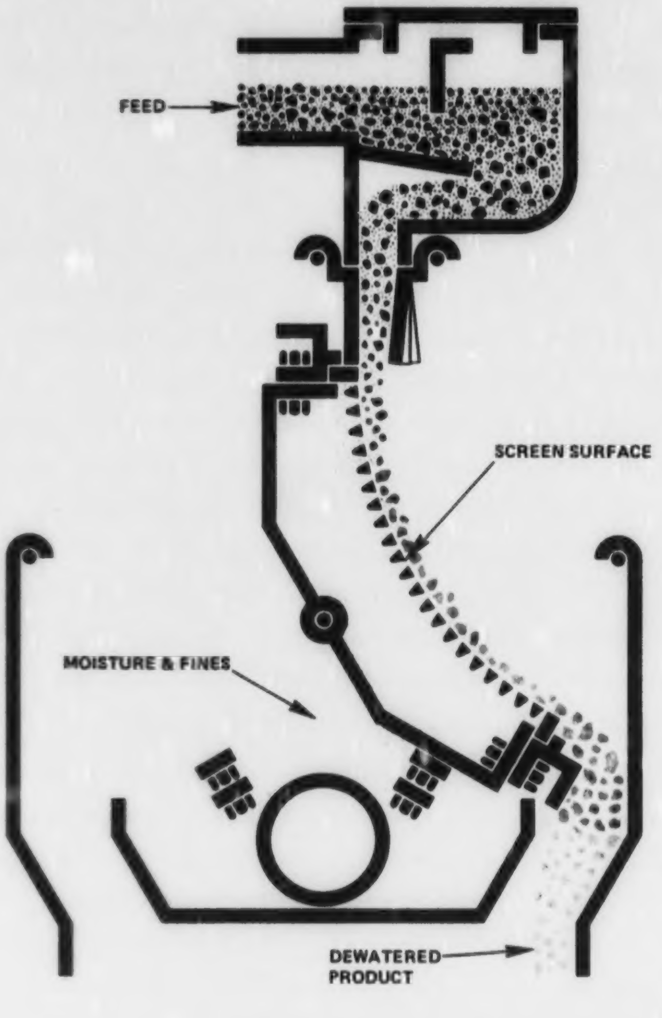


Figure 8-7
Sieve Bend

Photo courtesy of Dorr-Oliver, Incorporated
DSM Screen^{tm} is a registered trademark
of Dorr-Oliver, Incorporated



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SCHEMATIC DIAGRAM
OF A SIEVE BEND

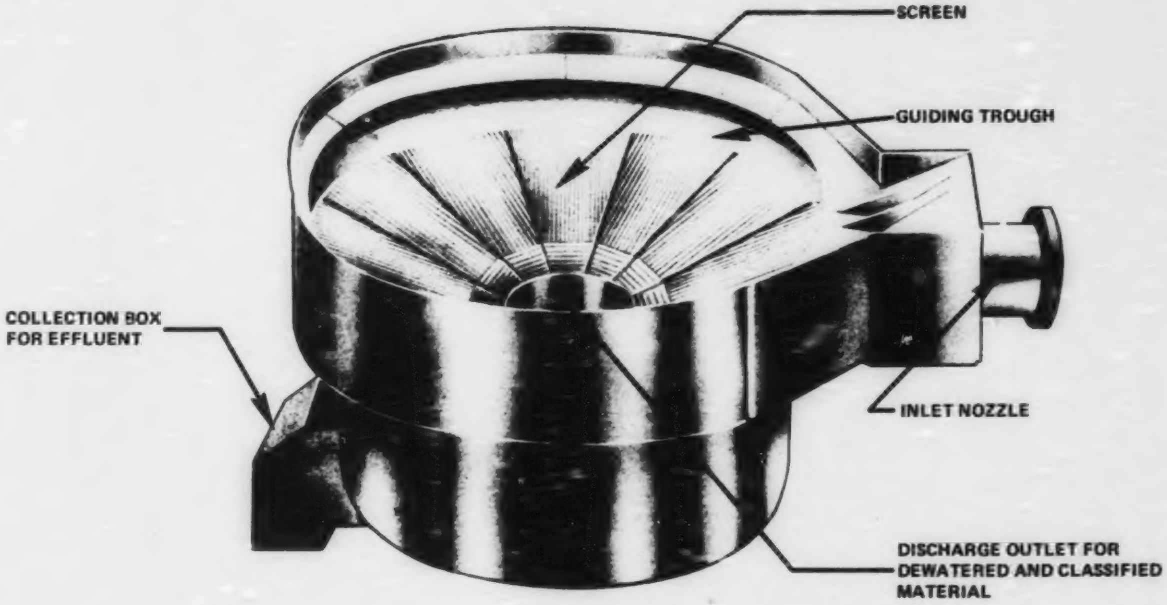
Figure 8-8. DCN

The feed slurry is introduced tangentially to the sieve bend by the means of a feed box. The feed flows by gravity down the arc of the surface and is discharged at approximately a 45 degree angle from the sieve bend. The actual separation obtained is approximately one-half the opening size in the surfaces.

The sieve bend is an inefficient device for sizing and dewatering compared to the vibrating screen. The overproduct will have a considerable amount of free water and the separation is not exact. The sieve bend will only function properly within a relatively narrow capacity range. A sieve bend used in conjunction with a vibrating screen will give a higher efficiency and will dewater better than a vibrating screen alone. The sieve bend is frequently used ahead of the vibrating screen as a replacement for the conventional stationary sieve in the flume in order to relieve the load on the vibrating screen. For approximate duplication of dewatering results, a screen used in conjunction with the sieve bend can be 2 to 4 feet shorter than a vibrating screen used alone.

A new type of vortex dewatering sieve which combines the characteristics found in cyclones, sieve bends, vibrating screens and cross flow screens has achieved significant results in several U.S. coal preparation plants during the last several years. The new dewatering device is called the Vor-Siv and is manufactured by the Perforated Metal Divisions of the National Standards Company under licensing agreement with the Polish Government. The Vor-Siv, shown in Figure 8-9, is a cross between a sieve bend and a centrifuge; it has no moving parts, yet provides highly efficient centrifugal dewatering action.

Separation of fine-grain solids through the use of the Vor-Siv is accomplished by the spiraling or vortex flow of


SCREEN
GUIDING TROUGH
COLLECTION BOX FOR EFFLUENT
INLET NOZZLE
DISCHARGE OUTLET FOR DEWATERED AND CLASSIFIED MATERIAL

Source: National Standard Company

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VOR-SIV

Figure 8-9.

DCN

a slurry over a stationary inverted cone-shaped wire screen. The feed is introduced into the Vor-Siv through a directional nozzle onto a circulating raceway. A certain minimum head is necessary to accelerate the feed slurry against the walls of the raceway, causing partial stratification of solids away from the associated water. As the semi-stratified feed stream loses energy, it spills from the raceway into a conical basket made of radially-slotted profile wire. The remaining energy in the feed stream creates a downward spiraling vortex flowing perpendicular to the slotted openings in the upper three-fourths of the basket. The solids flow down the screen to a discharge outlet at the point of the vortex while the liquid with the undersized particles flows through the fine slits of the screen. The Vor-Siv is reportedly capable of performing several tasks such as classifying, desliming, scalping and dewatering prior to the vibrating screen or centrifuge process. However, to date, the most common use for the Vor-Siv has been the dewatering of clean coal prior to centrifuging.

Comparisons of generally accepted sieve bend and cross flow screen applications and Vor-Siv applications are of interest. Sieves and cross-flows with 28-mesh sizing capability are generally assumed to have a capacity of about 30 to 40 gpm per square foot of wire surface. Some applications of sieve bends and cross-flows have been as low as 20 gpm per square foot of screen area while most Vor-Sivs are operating in the nominal range of 50 to 55 gpm per square foot. Feed rates on sieve bends of 30 to 40 gpm per minute and Vor-Sivs at 50 to 55 or even 70 gpm can be expected to produce moisture in high 20 and low 30 percentile. A Vor-Siv at 70 gpm separating at 28-mesh can reduce moisture to about 28%. Generally 34 to 38 percent surface moisture can be expected from sieve bend and cross-flow screen applications.

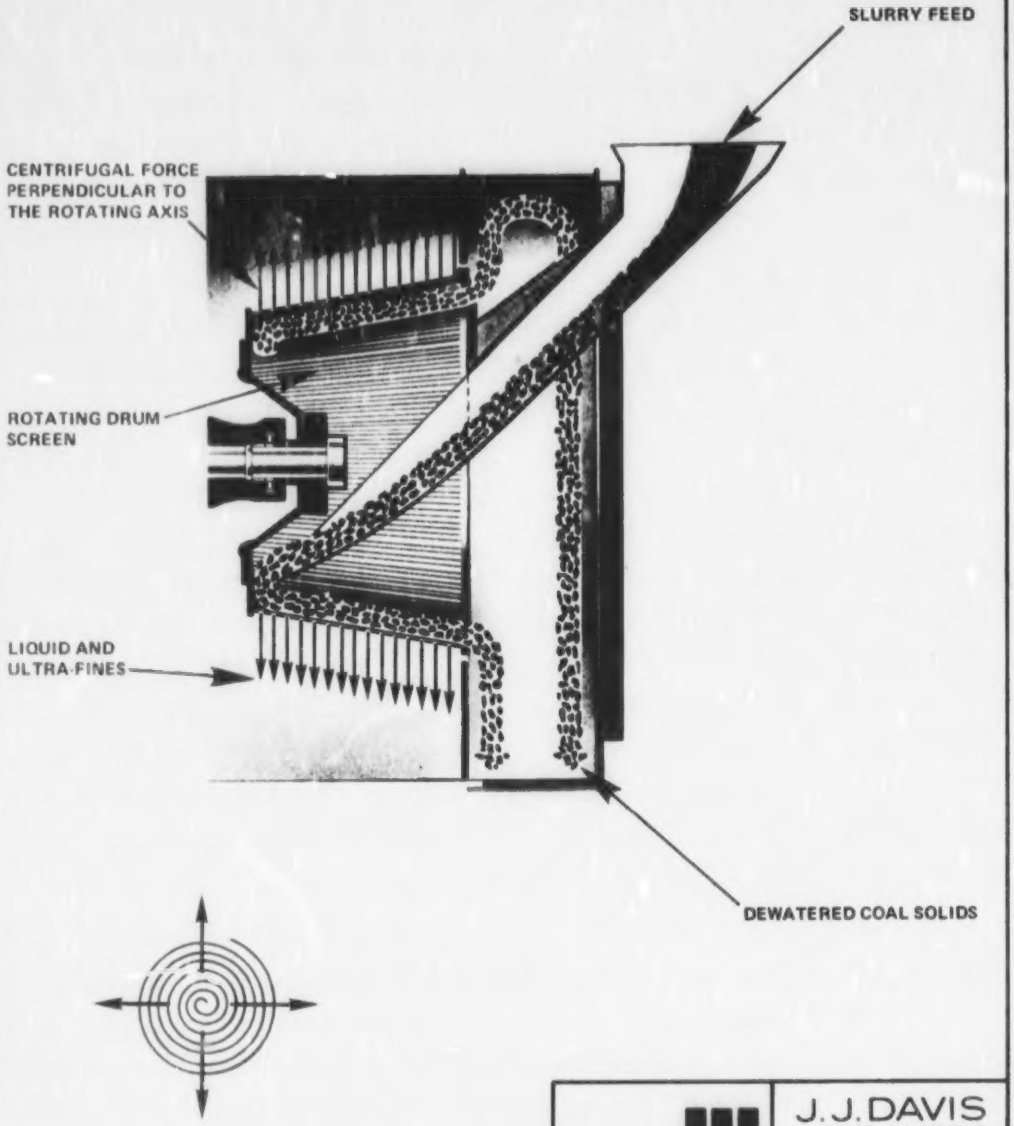
8.2.3 Centrifugal Dewatering

In a centrifuge, the coal and water are subjected to a spinning action which usually increases in intensity as the coal progresses through the machine. The spinning action, or centrifugal force that is induced tears the water away from the coal particles and produces a dewatered coal.

Centrifugal force is widely used when a force greater than that of gravity is desired for separation of solids and fluids of different densities, i.e., coal and water. A centrifugal force is created by moving a mass in a curved path. The force is exerted in a direction away from the center or curvature of the path. The centripetal force is a force applied to the moving mass in the direction toward the center of the curvature which causes the mass to travel in a curved path. If these forces are equal, the particle continues to rotate in the circular path around the center. If these forces are not equal, the particle passes through the screen and exits the device as fine size coal. Figure 8-10 graphically depicts the centrifugal force activity within a horizontal centrifuge.

In addition to the centrifugal force, the initial impact of the coal particles against the screen surface and the subsequent impact of the coal against coal plays an important part in the dewatering process within a centrifuge by breaking down the surface tensions between the coal solids and the water.

The effectiveness of the dewatering action for any particular machine is governed by the size consist of the coal feed and the centrifugal force imparted to the water



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CENTRIFUGAL FORCE DIAGRAM

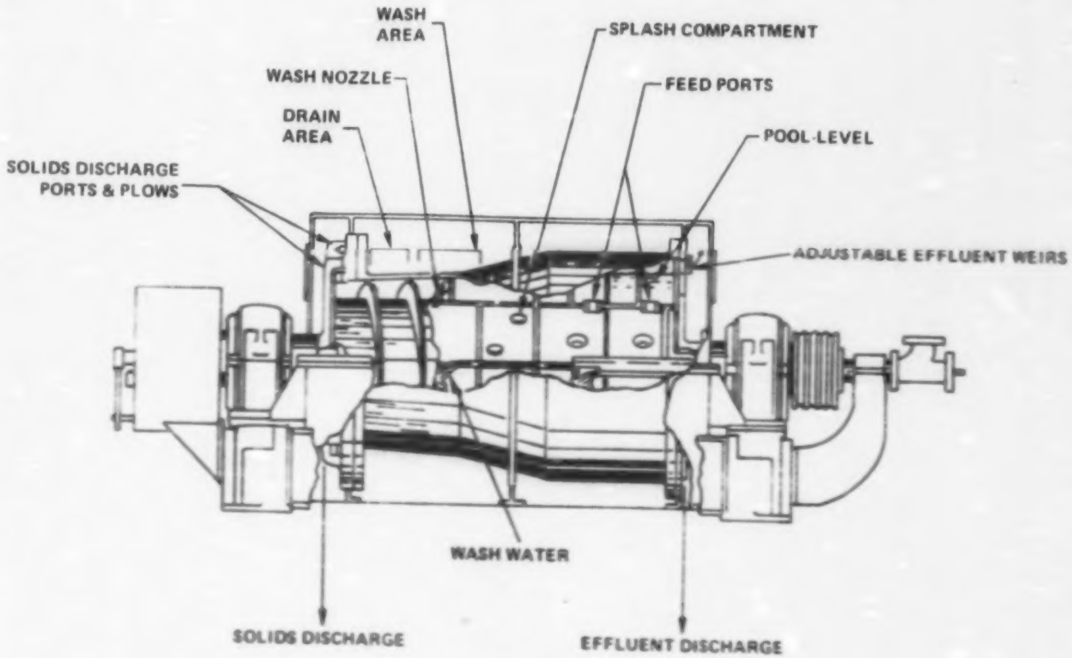
Figure 8-10 DCN

on the coal. Fine coal has a larger surface area per unit weight than coarse coal so its capacity for retaining moisture is much greater: As the quantity of fines entering a centrifuge increases, the cake moisture increases. As the percentage of fines in the slurry feed increases, longer centrifuging time or increased centrifugal force is required to maintain a cake or minimum moisture content.

Since the centrifugal force speeds up the separation of the solids from the liquid, it would seem logical to design machines for maximum centrifugal force. Pure centrifugal force is not, however, the only consideration. While centrifugal force helps solids settle, this same force is the enemy of solid discharge. Discharging coal particles becomes more difficult as the centrifugal force increases. For example, at 3,000 gravities and one ton per hour solids throughput, the discharge scroll of a solid bowl centrifuge is in effect pushing 3,000 tons of coal solids per hour up the drainage duct and consuming a great deal of energy in the process. Additionally, when centrifuges are operated in the higher force ranges, tremendous pressures are set up between the solids and the centrifuge bowl creating high frictional forces which combine with the very abrasive characteristics of the coal causing costly machine wear.

In general, three types of centrifuges are currently being used in the U.S. to dewater fine bituminous coal. These include the solid bowl or Bird, the perforated basket machines and the vibrating basket machines (both horizontal and vertical axles). These major types are discussed briefly in the paragraphs that follow:

- Solid Bowl Centrifuges, shown in an example in Figure 8-11. The two principal elements of the solid bowl centrifuge are the contoured rotating



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BIRD SOLID BOWL
CENTRIFUGE

Figure 8-11 DCN

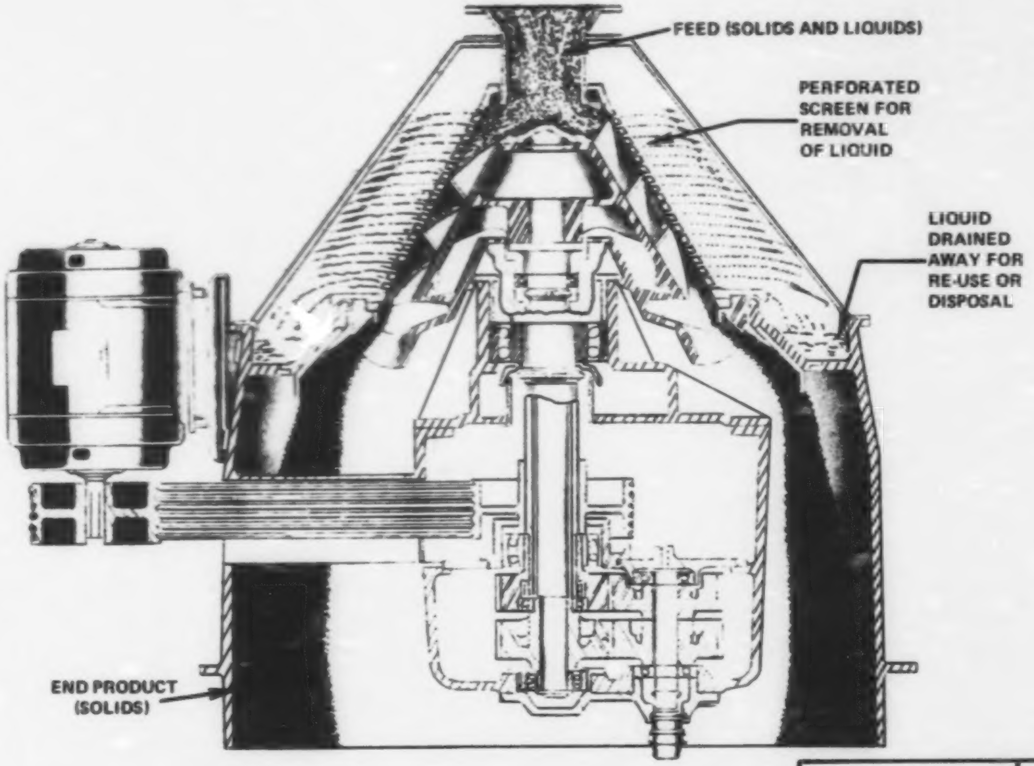
bowl which is the settling vessel and the conveyor or scroll which discharges the settled solids. The bowl has adjustable overflow weirs at its larger end for the discharge of the effluent. The solids are discharged at the opposite end through fixed ports. As the bowl rotates, the centrifugal force causes the slurry to form an annular pool, the depth of which is determined by the adjustment of the effluent weirs. The solids discharge end of the bowl is reduced in diameter so that it is not submerged in the pool and thus forms a drainage deck for dewatering the solids as they are conveyed across it by the scroll. The principal advantage of the solid bowl centrifuge is that is can be used to dewater very dilute fine slurries. However, this machine requires considerable power because it must accelerate the water load as well as the solids, and because the scroll must push the solids up to the discharge ports.

- Perforated Centrifuges are shown in Figure 8-12 which depicts a perforated basket centrifuge with a transport device, and Table 8-10 highlights typical performance characteristics of perforate basket centrifuges. These units have two rotating conical drums. One drum turns inside the other at a slightly slower speed. The outer drum or basket is usually made of stainless steel wire with replaceable screens mounted on its inner surface. The inner drum or scraper carries the blades which move the coal downward to the discharge area. The wet coal enters the machine

Table 8-10

36 In. Diameter Positive Discharge Perforate
Basket Contrifuge Performance

- Feed--65 tph, ¼ x 0"--20% to 35% surface moisture
- % Recovery--90% depending upon friability of coal
- % Product Moisture--6% surface moisture
- Motor Requirements--50 hp, 180 rpm, normal starting torque
- Operating Speed Range--550 rpm to 750 rpm
- Approximate G Forces Developed--150 to 300


FEED (SOLIDS AND LIQUIDS)
PERFORATED SCREEN FOR REMOVAL OF LIQUID
LIQUID DRAINED AWAY FOR RE-USE OR DISPOSAL
END PRODUCT (SOLIDS)

Source: Centrifugal and Mechanical Industries, Inc.

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PERFORATE
BASKET
CENTRIFUGE

Figure 8-12. DCN

at the top where it falls on the apex of the cone and the centrifugal force developed by the rotating cone throws the coal-water mixture against the screen. The water passes through the perforations and is collected in an effluent chamber. The coal is gradually worked to the bottom by the scraper where it drops out by gravity.

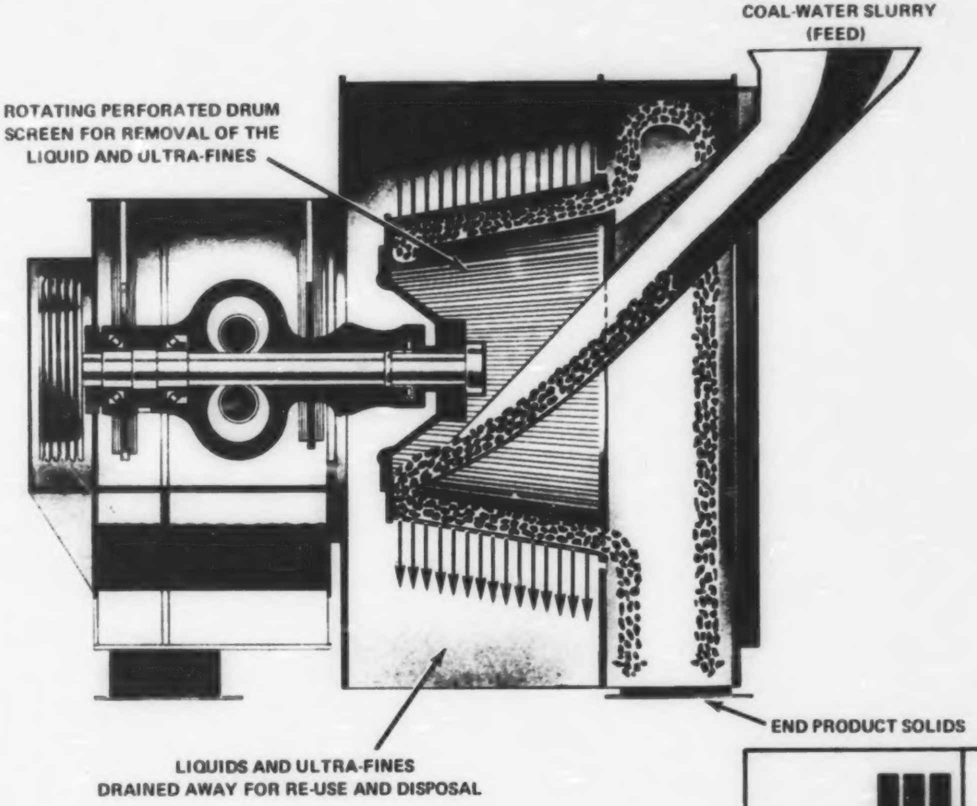
- Vibrating Basket Centrifuges are displayed in Figures 8-13 and 8-14 which depict perforated basket vibrating centrifuges. Typical reference data for these units are shown in Table 8-11. These vibrating basket centrifuges, whether horizontal or vertical, are the most common units being installed in modern preparation plants.

Table 8-11

Typical Performance Data for Vertical Vibrating Basket Centrifuges

- Feed Range - 60 to 150 tph
- Sizes Handled 1½" to 48 Mesh
- Horsepower - 25 - 40 hp drive motor,
  5 hp Vibration motor
- % Recovery - 97% or higher depending upon friability
  of coal
- Operating Basket Speeds - 200 to 450 rpm
- Approximate G forces developed - 25 to 120
- Feed Size - ¼" x 28 Mesh

These units differ from other perforated basket machines in that the rotating basket is vibrated in such a manner that the coal solids are expelled from the machine without the use of a transport device. The slurry feed passes down an inlet chute where it is gently distributed onto the inner surface of the screen basket. The rotating screen basket is kept in axial vibratory motion by a vibrating unit. The axial vibrations move the coal solids towards the larger diameter of the basket. In addition, the vibrating action keeps the basket opening clear and constantly loosens up the cake which improves the dewatering


COAL-WATER SLURRY
(FEED)
ROTATING PERFORATED DRUM SCREEN FOR REMOVAL OF THE LIQUID AND ULTRA-FINES
END PRODUCT SOLIDS
LIQUIDS AND ULTRA-FINES DRAINED AWAY FOR RE-USE AND DISPOSAL

Source: McNally-Pittsburg

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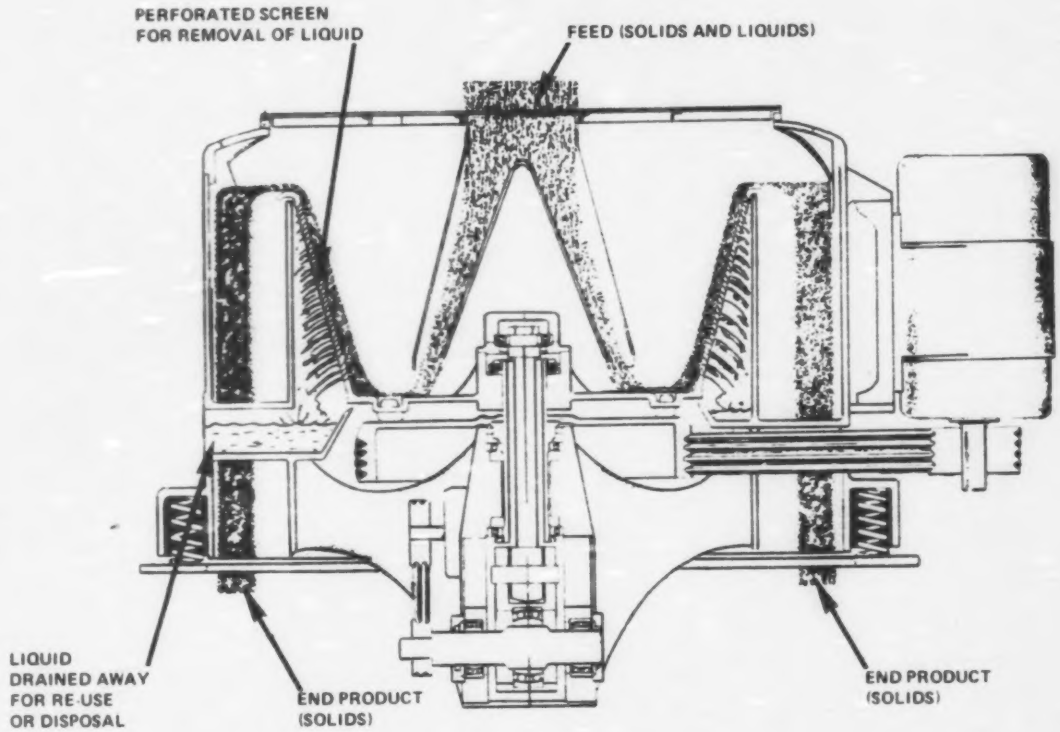
HORIZONTAL VIBRATING BASKET CENTRIFUGE

Figure 8-13. DCN


PERFORATED SCREEN FOR REMOVAL OF LIQUID
FEED (SOLIDS AND LIQUIDS)
LIQUID DRAINED AWAY FOR RE-USE OR DISPOSAL
END PRODUCT (SOLIDS)
END PRODUCT (SOLIDS)

Source: Centrifugal and Mechanical Industries, Inc.

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VERTICAL VIBRATING
BASKET CENTRIFUGE

Figure 8-14. DCN

action of the centrifuge. The dewatered solids which are thrown out at the large diameter end of the screen basket fall freely down to the collection belt. The liquid which is centrifuged out is ejected at the side. These machines are not operated at as high a speed as those with transport devices, therefore the product moisture is usually higher. However, machine wear is low, horsepower requirements are less and there is little or no product degradation.

8.2.4 Filtration

Dewatering by filtration is coming to play a major role in all wet cleaning plants. The recovery of clean coal solids and refuse solids from the fine coal circuit is the primary function of these filters. The filters process a suspension with a high percentage of coal or refuse solids and separate the water to produce a compact wet cake with an approximate surface moisture of 18 to 40 percent, depending upon the size consist of the feed.

Coal and refuse slurries have been successfully dewatered by both vacuum filters and pressure filters. The most common filtering system found in the coal preparation plants in this country is the vacuum filter. The separation of the solids on a vacuum filter is accomplished by placing a filter surface in the suspension and applying a suction behind the filter to draw the water and solids to the filter, thereby retaining the solids on the surface and drawing the water through. The solids trapped on the filter (the cake) are slowly rotated approximately 120 degrees out of the slurry mixture to permit the cake to dry. The cake is then lifted off the filter surface before the surface re-enters the suspension by increasing the air pressure behind the filter to loosen the cake and then removing the cake from the surface with scrapers.

There are two basic types of vacuum filters in use--the disc filter and the drum filter. Figure 8-15 depicts a typcial disc-type filter and its associated activities. Disc-type filters range in diameters up to 13½ feet with as many filter discs as necessary to provide a sufficient amount of filtering surface. The discs operate in a trough with some type of agitating device to help keep the solids in suspension.

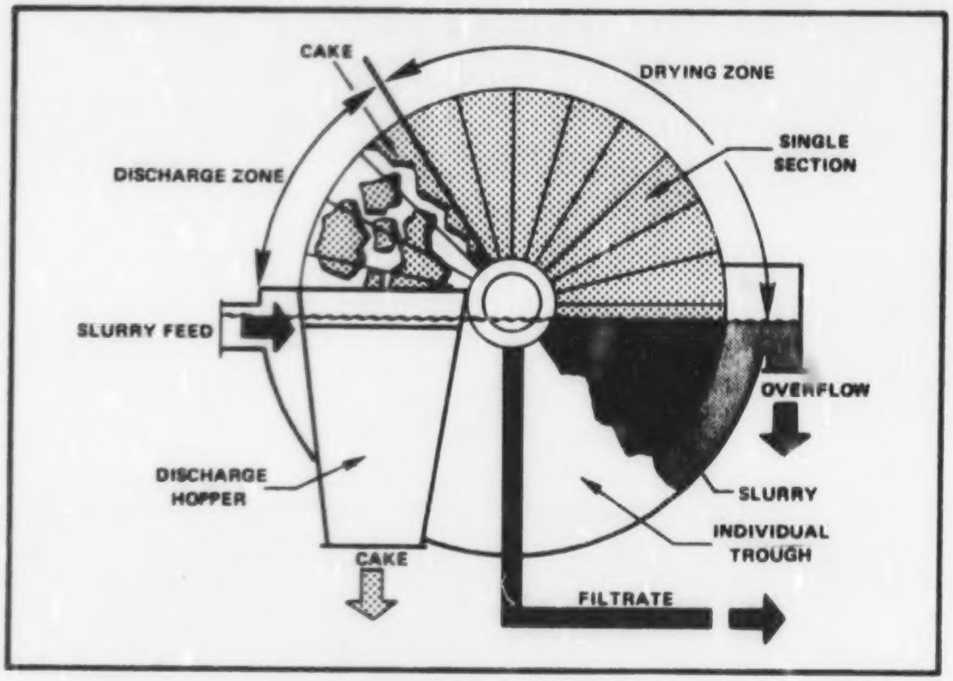


Figure 8-15
Operational Diagram of a Coal Vacuum Filter

Figure 8-16 depicts the individual filter compartments for a new disc-type filter and Figure 8-17 shows the standard disc filter in a preparation plant. The disc-type filter has several advantages over the drum-type filter: the disc filters are lower in initial capital cost, require

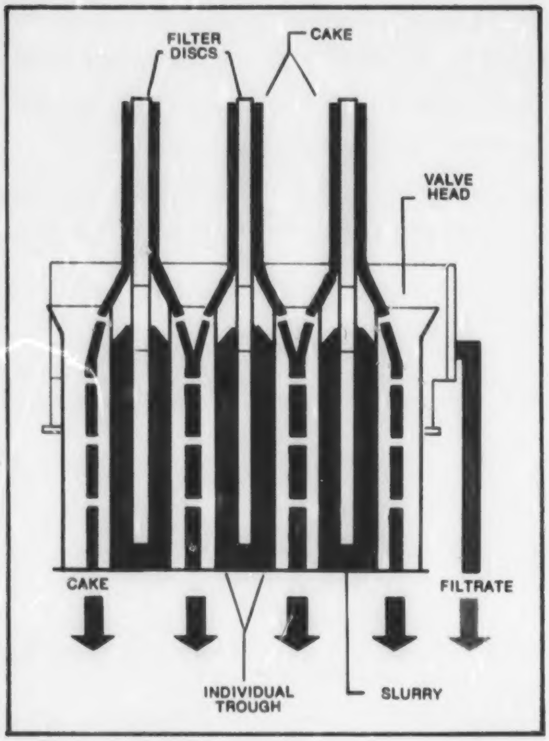


Figure 8-16
Individual Filter Compartments

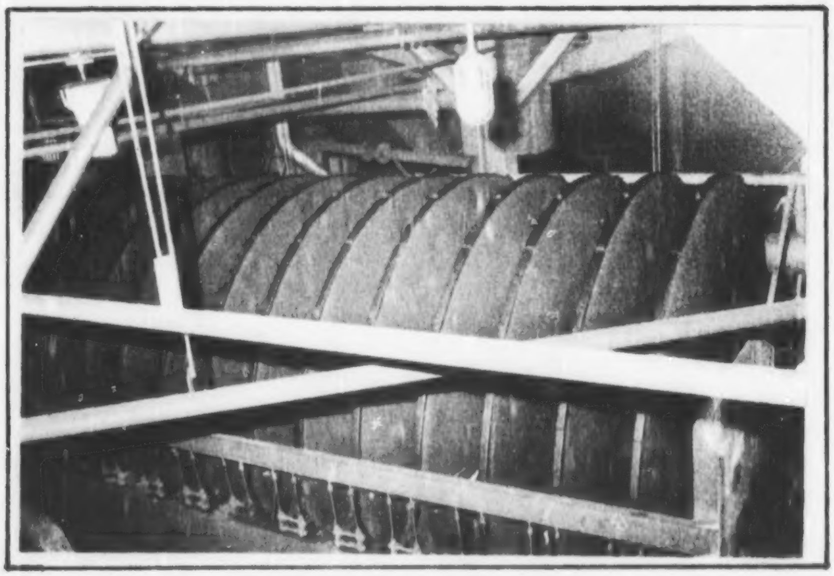


Figure 8-17
Standard Vacuum Filter Installation

less floor space per filter capacity and maintenance costs are less.

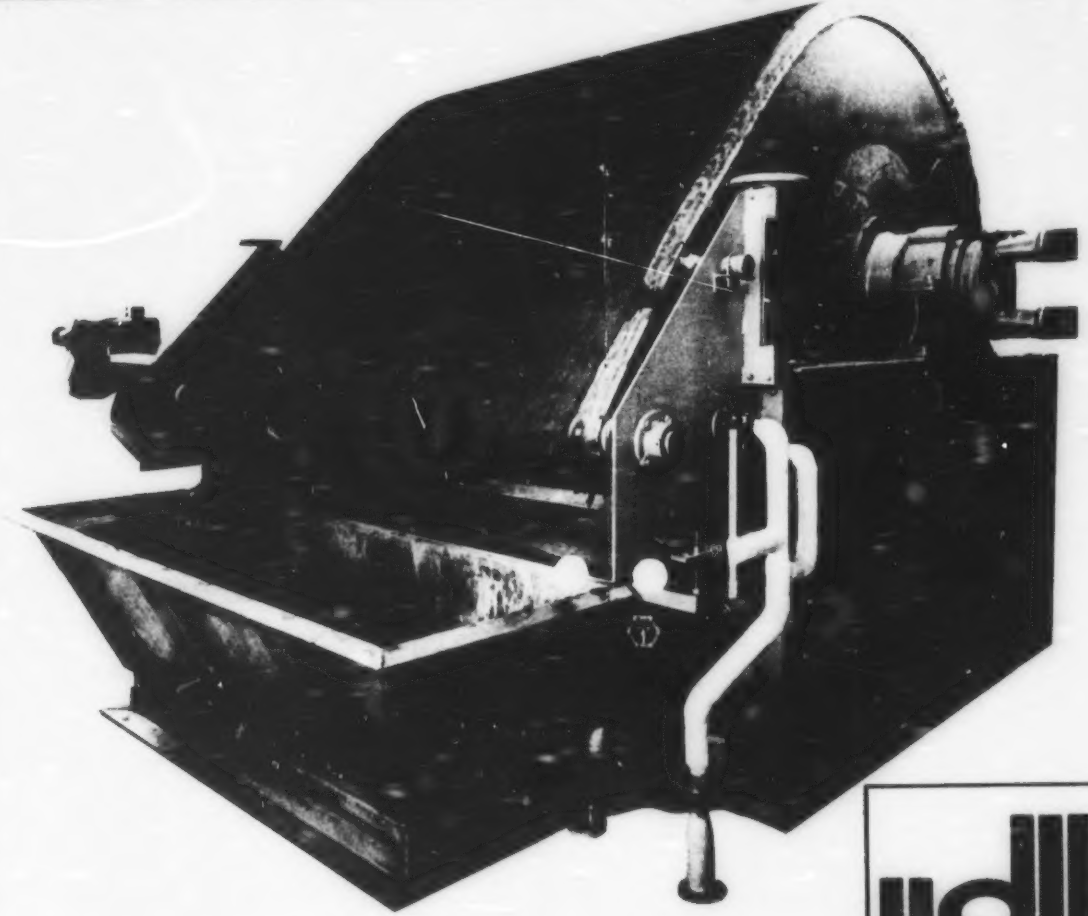
The operating principles of drum-type filters are similar to the disc-type filter except the filter surface is one long drum of varying lengths and diameters. Figure 8-18 shows a profile of the drum-type filter. The only advantage to a drum-type filter over the disc-type is that if a thin filter cake is being produced, the drum-type will generally permit more complete removal of the filter cake.

Although pressure filters have found wide acceptance outside the United States, their extremely high initial cost and lack of automation has made them unacceptable to the American coal preparation industry. The pressure filter produces a relatively dry filter cake and a solid free effluent (less than 1000 ppm solids). Table 8-12 compares the relative differences between a pressure filter and a disc filter producing 30 tons per hour solids from a 30% solids feed.

Table 8-12
Pressure vs Disc Filter

	Pressure Filter	Disc Filter
Feed	30% Solids	30% Solids
Dry Tons Per Hour	30	30
Cake Moisture	20-23%	34-40%
Capital	$2.4 million	$200,000

It is obvious that although the pressure filter produces a much more desirable cake, the capital cost is



Source: AMETEK

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Rotary Drum
Coal Filter

Figure 8 18

DCN

appreciably higher than a disc filter. The operating costs are also higher because of the semi-automatic, cyclical nature of the filter which requires nearly constant attendance by an operator.

The performance characteristics of any of the filters discussed above are dependent upon a multitude of variables, the most important of these are listed and discussed in the paragraphs that follow:

- Filter feed solids concentration--is perhaps the most important variable to be considered. A general plot of the dry cake output vs feed solids concentration is shown in Figure 8-19. The coal slurry exhibits a sharp incremental rate increase of filtration rates above 35 percent solids. Above the approximately 58 percent solids, the transport of coal slurry to the filter is difficult. Controlling the solids concentration between the limits of 45 to 55 percent by the use of thickening devices such as cyclones and classifiers minimizes filter area requirements and filter operating costs.

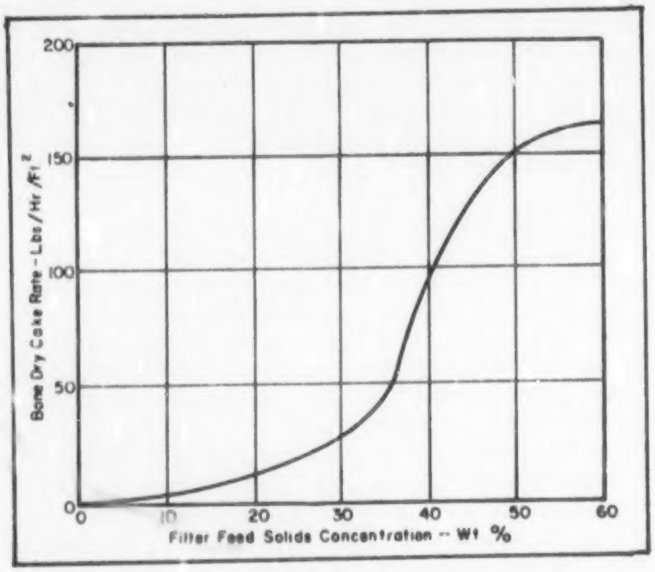


Figure 8-19
Filtration Rate vs Feed Solids

- Size consists of solids in feed--for the usual minus 28-mesh clean coal slurry, the general filtration rate curve shown in Figure 8-19 holds true. However, as particle size decreases, the feed solids concentrations at which a sharp increase in filtration rate occurs decreases, and there is a decrease in the maximum obtainable feed solids concentration. However, it has been established that the minus 200-mesh portion of the solids have the most significant impact upon filtration rates. The minus 200-mesh solids contain a very high percentage of clay or slimes which reduces the permeability of the cake, reduces the filtration rate and increases the cake moisture.

- Filter media--contributes to a great extent to the filtration rate, cake moisture content and filtrate clarity of the filtering operation. The three most effective filter media in use in modern preparation plants are stainless wire mesh, saran and polyethylene. The filter characteristics of each of these filter media are similar. They all generally permit the minus 200-mesh particles to pass, have minimum blinding characteristics and good cake release characteristics. The primary differences between any one medium and another relate to initial capital cost and filter life. Stainless steel wire may have an initial capital cost of $3.00 plus per square foot of surface area and a filter life of up to three years. On the other hand, saran and polyethylene may have a filter life as short as three months.

- Cake air requirements--are primarily a function of cycle time and coal particle size. However, coal cakes of minus 28-mesh particles generally require an air flow expressed as three cubic feet of free air per minute per square foot of area (3 cfm/ft^2)-compressible. On minus 28-mesh coal, at least 22-in. mercury vacuum must be generated to obtain the minimum cake moistures and the maximum cake rates--3 cfm/ft^2, permits a vacuum differential of at least 22-in. mercury. Because coal cakes are essentially non-compressible, increasing the vacuum differential would not be economical either in increased solids recovery or decreased cake moisture control.

Figure 8-20 is a schematic diagram of a fine size coal filter installation and depicts the degree of complexity of this portion of the fine size coal dewatering and drying module. The complete description of the entire filtering circuit is beyond the scope of the presentation; however, when one considers the cost of operating a filter circuit *vs* the recovery of between 50 and 100 tph of solids, it is not difficult to comprehend the high cost of fine size coal dewatering.

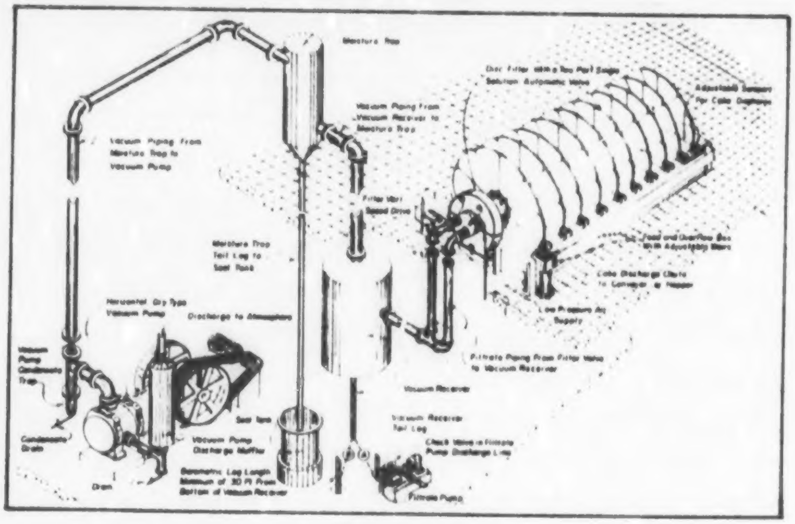

Moisture Trap
Vacuum Piping From Moisture Trap to Vacuum Pump
Vacuum Piping From Vacuum Receiver to Moisture Trap
Disc Filter With a Two Part Single Solution Automatic Valve
Adjustable Snappers For Cake Discharge
Filter Vari Speed Drive
Moisture Trap Tail Leg to Seal Tank
Feed and Overflow Box With Adjustable Weirs
Cake Discharge Chute to Conveyor or Hopper
Horizontal Dry Type Vacuum Pump
Discharge to Atmosphere
Low Pressure Air Supply
Filtrate Piping From Filter Valve to Vacuum Receiver
Vacuum Pump Condensate Trap
Vacuum Receiver
Seal Tank
Vacuum Receiver Tail Leg
Condensate Drain
Vacuum Pump Discharge Muffler
Check Valve in Filtrate Pump Discharge Line
Barometric Leg Length Minimum of 30 Ft From Bottom of Vacuum Receiver
Drain
Filtrate Pump

Figure 8-20

Schematic Diagram of a Typical Fine Coal Filter Circuit

8.2.5 Thermal Drying

As discussed in the other portions of Section 8.2, surface moisture of the coarse coal product may be removed by natural drainage and/or screening; however, for the intermediate and fine size coal and refuse sizes, the additional step of centrifugation or filtration is usually required. When a surface moisture of intermediate and fine sizes of coal is required which goes beyond the limits of the mechanical devices discussed, the remaining moisture must be removed by evaporation in some form of a heat dryer. Thermal coal dryers may be grouped into six basic types. These are:

- fluidized bed,
- suspension or flash,
- multi-louver,
- vertical tray and cascade,
- continuous carrier or screen and
- drum or rotary type.

Coal industry trends in the application of the preceding types of drying facilities have exhibited: expanding general application of coal drying (from 32 to 57 million tons between 1958 and 1964) and expanding specific application of fluidized bed coal drying (from 1 to 38% of all coal dryers between 1958 and 1964). However, while in 1972 there were 184 preparation plants employing thermal drying units, in 1973 that number had decreased to 162. Likewise, the thermally dried tonnage of bituminous coal and lignite fell from 53 million tons in 1972 to 46 million tons in 1973. Indications are that during 1974 less than 10% of the total production of bituminous coal and lignite was thermally dried.

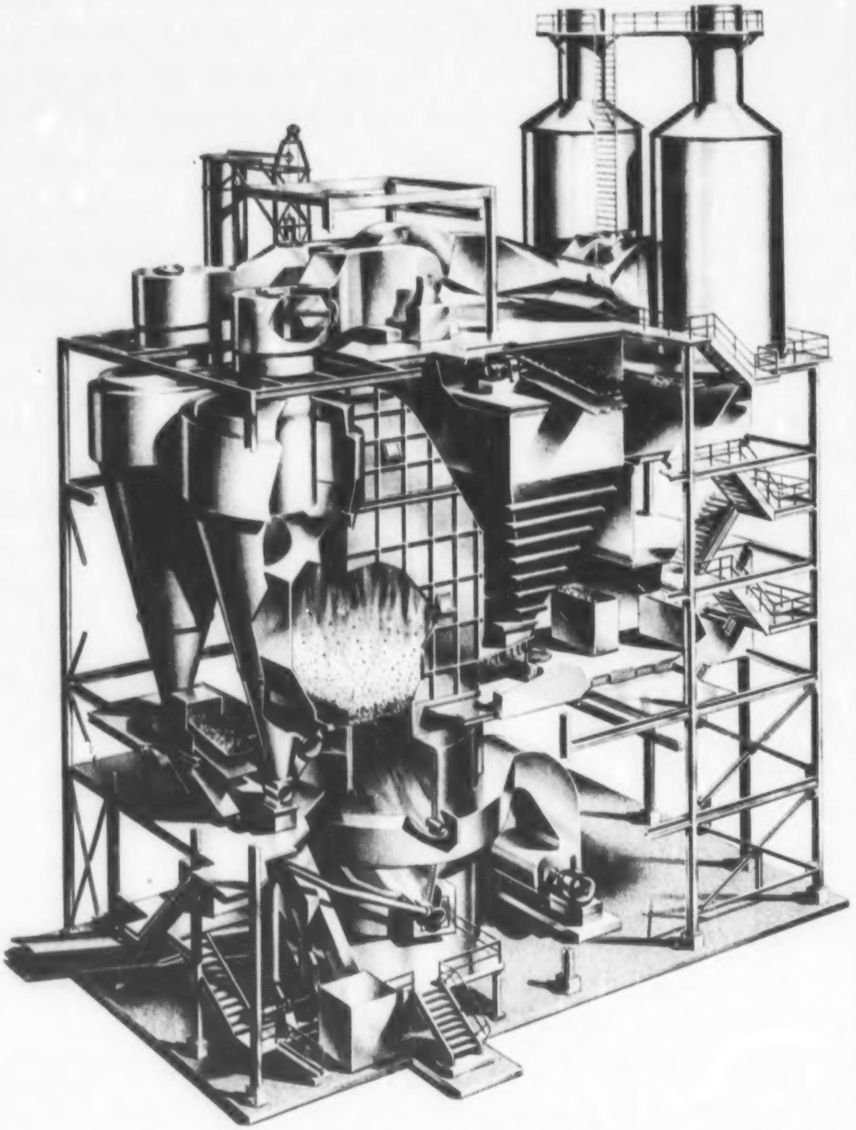
In 1973, the distribution of the six types of dryers discussed was as follows:

- fluidized bed (66),
- multi-louver (16),
- rotary (36),
- screen (12),
- suspension or flash (31) and
- vertical tray and cascade (1),

for a total of 162 thermal drying units.

All industrial coal dryers now in use are the continuous direct contact type which employ convection as a major means of heat transfer. Thus, hot gases and wet coal are brought into intimate contact with each other on a continuous gas flow--coal feed basis. The hot gases used for thermal drying are usually the gaseous combustion effluent from a coal burner. Sufficient excess air is fed to the burner to generate an off gas of the optimum temperature range for coal drying. This gas contains unburned oxygen and nitrogen from the burner air feed and carbon dioxide and water vapor as gaseous combustion products. A fan or blower is used to force the hot gas up through the fluidized bed of drying coal. A knowledge of the behavior of the fluidized coal bed and of the drying properties of the combustion of gas over a range of temperatures is necessary for an understanding of thermal coal drying and is beyond the scope of this publication. A typical coal dryer is shown in Figure 8-21.

A multitude of factors affect the performance capability of a thermal coal dryer: drying temperature, heat, fuel, inlet temperature, air volume and dryer size. However, the greatest single factor affecting performance is temperature. Temperature in the drying zone should always be as high as safety will permit. When low temperatures are used, sensible heat losses in the exhaust gas are usually greatly increased because a high air flow is needed to deliver the required heat. Moreover, lower temperature means low thermal efficiency, higher fuel and power requirements and increased amounts of dust carryout. Coal drying temperatures vary according to the type of dryer, coal and drying conditions. For example, a cloud of minus 200-mesh coal dust containing 32% volatile matter will ignite at approximately 1,100 degrees



The No. 10 Flowdryer includes exceptional features and reveals extensive flexibility of Flowdryer to meet practically any production requirement or air control standards. Among special features of this unit capable of handling 594 tph at 11.6 percent moisture, feed size range of 6 mesh to 0 and achieve 53 tph evaporation rate are: • an unusually high pressure drop through drying bed, resulting in high velocity drying gases breaking up and effectively drying filter cake balls, • an oversize furnace with the added volume providing better mixing of drying gas with product, uniform temperature and pressure under drying bed, and longer furnace life; • a band of high alumina refractories at burner level and super duty refractories in remainder of the furnace walls for minimal wall erosion; • judicious use of stainless steel for free flow of materials; and • special high energy scrubbers to meet air pollution control standards. Scrubbers employ stack testing extensions for sampling emission.

Figure 8-21

Typical Thermal Coal Dryer

Source: McNally-Pittsburg Manufacturing Corp.

Fahrenheit, while a layer of such dust will ignite at about 350 degrees Fahrenheit. The ignition temperatures discussed are above normal coal dryer discharge temperatures and do not take into account the spontaneous heating of coal which is influenced by particle size, volatility, mineral matter, moisture and temperature. For example. bituminous coal which is heated to only 140 to 150 degrees Fahrenheit can catch on fire from spontaneous combustion within hours after being loaded into railroad cars.

There has been much written on the design theory and operational characteristics of each of the various types of thermal coal driers--a detailed discussion of the inner workings of these units is beyond the scope of this work. However, the following discussion will outline the functioning of fluidized bed dryers. Basically, the principle of fluid bed drying is uncomplicated: Air heated by either a pulverized or stoker-fired coal furnace is pulled upward through a constriction plate by a negative pressure suction fan. The heated air passing through the orifices of the constriction plate creates extremely high velocity air currents which suspend the coal above the plate in a buoyant effect and cause the mass to act like a turbulent liquid. This "liquid" flows at a relatively even depth from the feed end to the discharge end of the dryer. In order to overcome the relatively high pressure drop, most dryers employ two fans. The intake fan pressurizes the furnace providing enough pressure to overcome the resistance to and through the restriction plate. An exhaust fan beyond the primary dust collector creates a suction, pulling the hot gases on through the collecting system and out the exhaust stack. It is assumed that all the drying gases pass through the dust collector, thereby preventing the loss of fines through leakage. The coarse dried material discharges from the dryer through a motorized conveyor-airlock. The fines which are suspended in the air stream are collected and usually recombined with the coarse material at the discharge.

The principle of fluidization as applied to the drying process has resulted in a thermally efficient method of moisture removal from the coal solids. The fluidized coal solids are completely surrounded by hot drying gases and intimate contact is obtained between the air and the coal. For every material there is a certain gas flow rate which will suspend the material so that its particles become disengaged and can be moved with a small amount of energy. While drying can be obtained in any phase of fluidization, the optimum condition is in the mild or incipient phase of fluidization. Operation at this point reduces dust loading, yet provides sufficient agitation to give good air to surface contact.

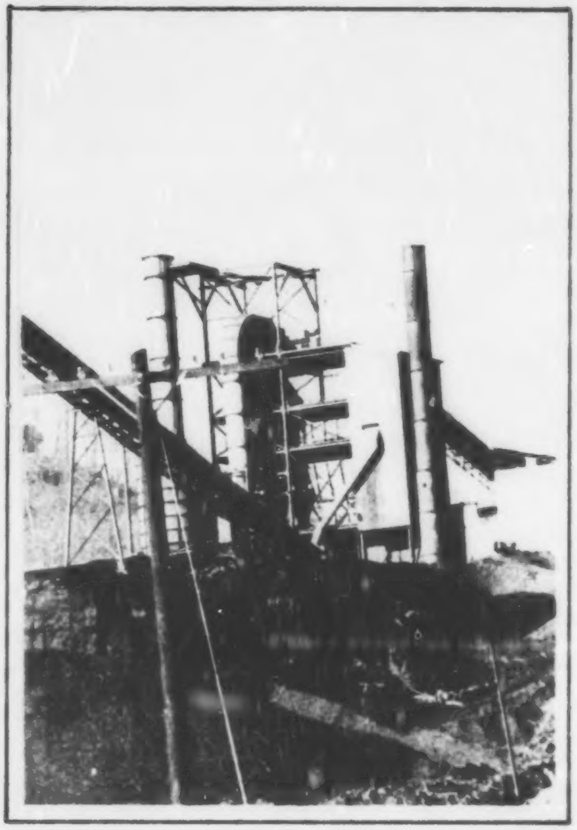
Air volume is controlled by sensing the amperes of the induced draft fan motor, and a balance is maintained by opening and closing the induced draft fan damper. The temperature is controlled by sensing the exhaust gas temperature of the dryer and controlling the burning rate of either the stoker or the pulverizer. The exhaust temperature is the prime controlling point; however, should the inlet temperature exceed the present high limit, the control will then switch the inlet temperature controller automatically and turn the air furnace to a low fire. Should either the furnace or dryer exhaust gas temperatures exceed a pre-set high limit, the drying system will fail and the following sequence of events will occur: a visual signal lamp will light up, a warning horn will sound, the furnace by-pass stack damper will open to by-pass the hot furnace gases to the stack and, to provide further insurance, a protection damper located between the air furnace and the dryer will close and isolate the dryer from the furnace completely--simultaneously a cooling damper will open to cool down the dryer. A central static pressure gauge is located in the control panel in the control room to indicate whether any plug-ups occur at various points throughout the system.

The feed rate of the dryer is controlled by a surge bin and variable speed screw feeders. As the rate of surge varies, level indicators located within the bin sense the level and increase or decrease the speed of the screw feeders to maintain balance within the dryer. Most dryers are designed to automtically handle load fluctuations and start and stop operations as encountered in normal preparation plant operations or in emergency shutdowns with a minimum of operator attention and maximum safety. Figure 8-22 shows a typical thermal dryer installation and Figure 8-23 highlights potential air pollution problems.

8.3 THICKENING COAL AND REFUSE SLURRIES

As indicated in Section 8.2, Methodologies of Dewatering and Drying the coal and refuse solids, there is usually considerable underflow from the screening or centrifuging processes. This underflow contains a percentage of coal or refuse solids that must be recovered. In addition, specific elements of the intermediate and fine size coal cleaning circuits discussed in Chapter 7 create very dilute slurries of coal or refuse products. In each instance, these dilute slurries must be thickened before they can effectively be further processed by filtration or if coarse enough by centrifugation. Of the devices used to thicken these slurries in the modern preparation plant, two merit discussion: hydraulic cyclones and classifiers.

Figure 8-22
The Thermal Dryer



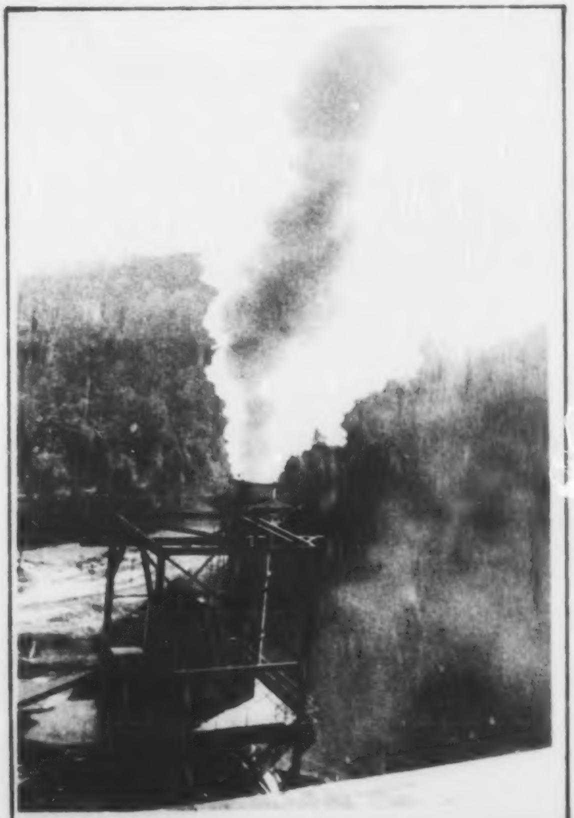


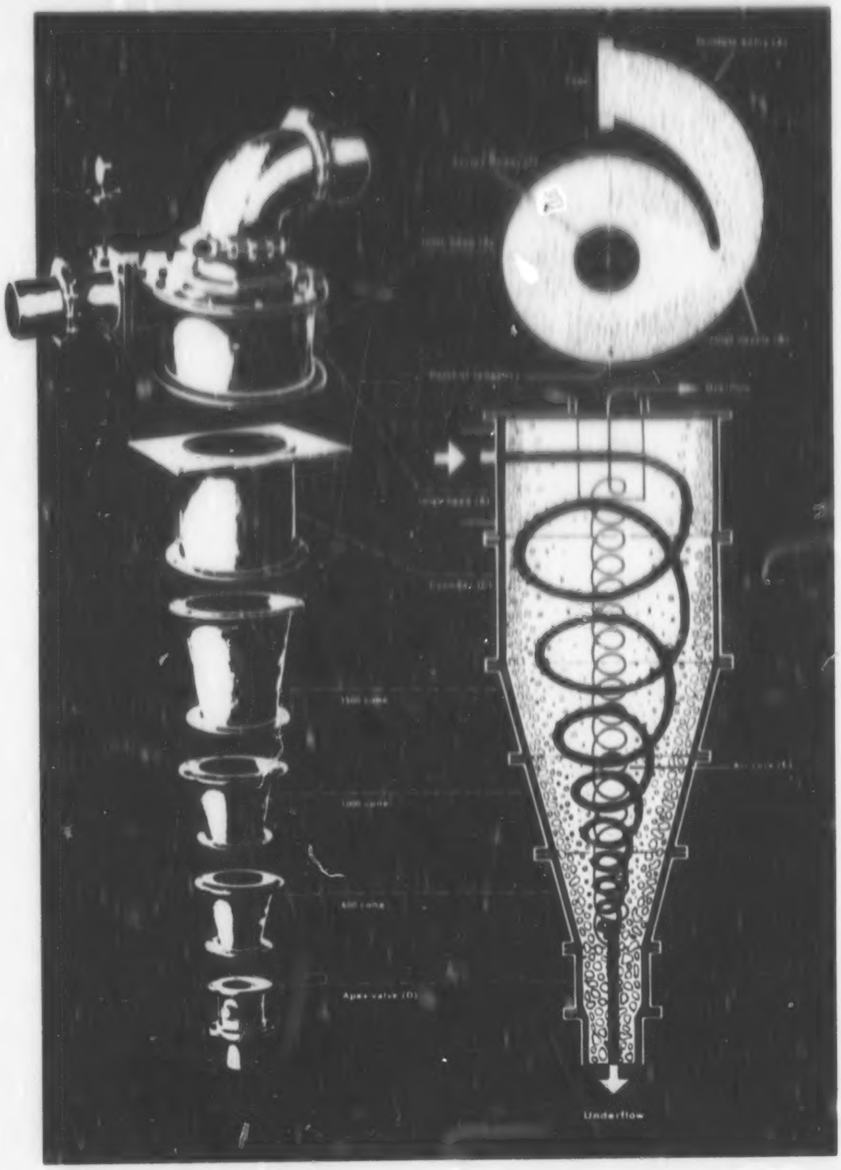
Figure 8-23
Obvious Air Pollution
Problems When Unchecked

8.3.1 Hydraulic Cyclones

In addition to the centrifuges discussed in Section 8.2.3, the cyclone thickener uses the principles of centrifugal force to thicken or classify coal or refuse solids and thereby aid in product dewatering. Cyclone thickeners are essentially hydraulic centrifuges: They are either used as a secondary dewatering circuit for intermediate coal sizes or as a primary circuit in dewatering fine size coal solids.

A cut-away view of a hydraulic cyclone is shown in Figure 8-24. The cyclone body generally consists of a short cylindrical section attached to an inverted truncated conical section. The apex of the conical section is referred to as the underflow orifice. A central overflow orifice or vortex finder is fitted to the base of the cone. Although the complex inner workings of the cyclone are not fully understood, there is a basic understanding of how the unit functions. The coal and water mixture enters the upper part of the cyclone tangentially at a high velocity through an orifice into the cylindrical section, thereby creating a centrifugal force field. The heavier particles move to the outside wall and slide downward to the apex of the cone and out the underflow orifice in a thickened slurry. The lighter particles, having less tendency to settle at the wall, are forced to the overflow by the upward velocities at the core of the cyclone. Figure 8-25 depicts the flow patterns within a cyclone.

The cyclone underflow sprays into a collecting trough and flows by gravity to the secondary dewatering process. The overflow, which may or may not need further processing, is controlled by an overflow valve as well as by the size of the underflow and overflow orifices. Normally the underflow volume is about 10 percent of the feed



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HYDRAULIC CYCLONE

Figure 8-24 DCN

volume. By closing down the overflow valve, back pressure is applied which forces more material out the underflow; the result is lower underflow concentrations and higher recovery of fine solids.

The performance characteristics of cyclone thickeners vary greatly with the actual and relative diameters of the upper and lower outlet valves as well as with the diameter of the inlet orifice. All hydraulic cyclones incorporate easy adjustment of these dimensions. The nature of the spigot discharge varies according to operating conditions. Under normal conditions the discharge is a peripheral whorl breaking into a spray as it leaves the spigot or nozzle. Subsequently, air enters the center of the whorl and discharges through the center of the similar whorl at the top of the overflow pipe. This air column is generally accepted as being continuous from bottom to top forming the core of the vortex. When the overflow tube projects to the level of the junction between the cylindrical and conical section, solids recovery is maximized.

Extensive experimentation has shown that although throughput with a given feed orifice increases with the increase in feedline pressure, solids recovery at the underflow does not increase. This is taken to be because the decreased time of residence within the cyclone counterbalances the increase in settlement rate resulting from the velocity increase. However, if the pressure increase is accompanied by a reduction in the nozzle area so as to keep resident time constant, solids recovery is increased. A decrease in the spigot diameter with no other changes increases pulp density in the underflow. If this reduction in diameter is carried too far, the air core is lost and solids elimination decreases sharply. A decrease in the diameter of the overflow pipe decreases the solids content of both overflow and nozzle products. Solids in overflow increase with the solids content of feed.

Cyclone thickeners are available in many sizes. The size chosen for a particular installation is directly dependent upon the size consist of the feed. For example, three inch diameter cyclones are used to process fine slurries containing particles generally having 8-mesh by 0 size range. The units are normally arranged in banks containing 22 cones each, with a common manifold in the one feed line and one overflow line. One bank of the cyclones will handle a flow of approximately 250 gpm of slurry at a feed pressure of 40 psi. The top size of feed to an 8 inch diameter cyclone should be less than 3/16 inch. The standard 8 inch diameter cyclone will process approximately 110 gpm of slurry at a feed pressure of 40 psi. The 8 inch diameter cyclones are normally arranged in banks of two, three or four cones with common feed and overflow manifolds.

The 14 inch diameter cyclone has a capacity of 325 gpm at a feed pressure of 40 psi and is designed to handle slurries with particles up to 1/4 inch. They may be operated as a single unit or connected in parallel to make up banks. Figure 8-25 displays a bank of 4 cyclones in an actual preparation plant. Typical performance data on a 14 inch diameter cyclone is shown in Table 8-13.

8.3.2 Classifiers

Classifiers are frequently used in coal preparation plants to assist in the dewatering of coal and refuse solids. However, their most typical operation is the pre-thickening of the refuse solids suspended in the plant water circuit prior to the thickening or filtering operations.

Table 8-13
Typical Performance of a 14-inch Diameter
Hydraulic Cyclone

Application: Thickening of 28 mesh by 0 fine coal slurry.
Feed Pressure: 25 psig **Flow:** 300 gpm per cyclone.

Size, Microns and Tyler Mesh	*Feed*	*Underflow*	*Overflow*
0– 20 Microns	27.0%	3.7%	53.8%
20– 44 Microns	12.0%	3.0%	22.4%
325–200 Mesh	9.0%	5.0%	13.5%
200–100 Mesh	15.0%	19.6%	9.7%
+ 100 Mesh	37.0%	68.7%	0.6%
	100.0%	100.0%	100.0%
Concentration by Weight	10.0%	46.0%	5.0%
Recovery		53.5%	

Remarks: Above results show typical 14-in. cyclone performance thickening feed to sludge screen or vacuum filter.

This function is primarily a sizing operation of the solids in suspension. These sizing classifiers do not require additional water besides that present in the slurry being treated. They utilize free-settling conditions to effect sizing as much as possible and are unaffected by the specific gravity and shape of the particles. The size at which a separation is made ranges from 20- to 300-mesh. Sizing classifiers are operated at the dilutions ranging from a solid content of 3 to 5 percent by weight if sizing is at the extreme fine end or up to 30 or 35 percent by weight if sizing is at the coarse end.

There are a variety of classifiers in use, but they may be grouped into two main types on the basis of the flow of the slurry: horizontal-current and vertical current. The most common type of classifier in use in coal cleaning plants is the horizontal-current mechanical type classifier. These types of classifiers generally have mechanical devices to agitate the slurry and to carry the settled solids away and are typified by the spiral or screw classifier, shown in Figure 8-26.

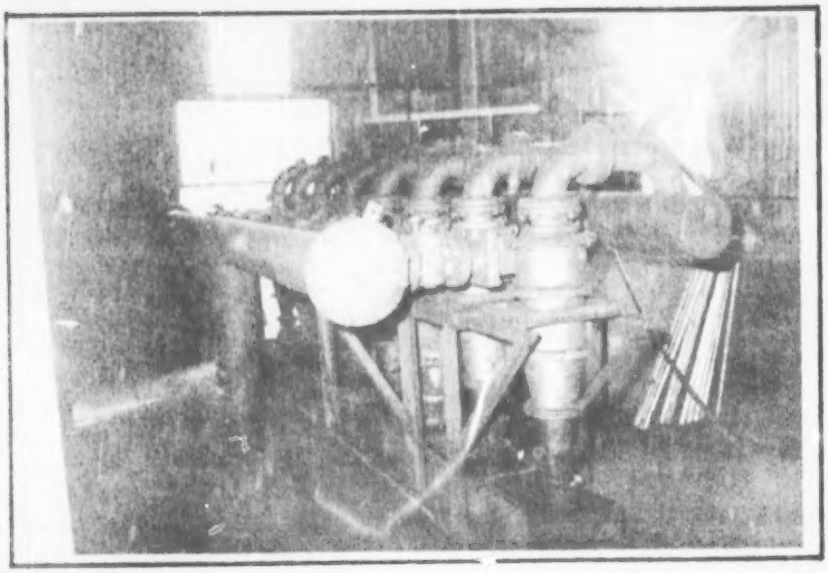

Figure 8-25
Typical Hydraulic Cyclone Installation

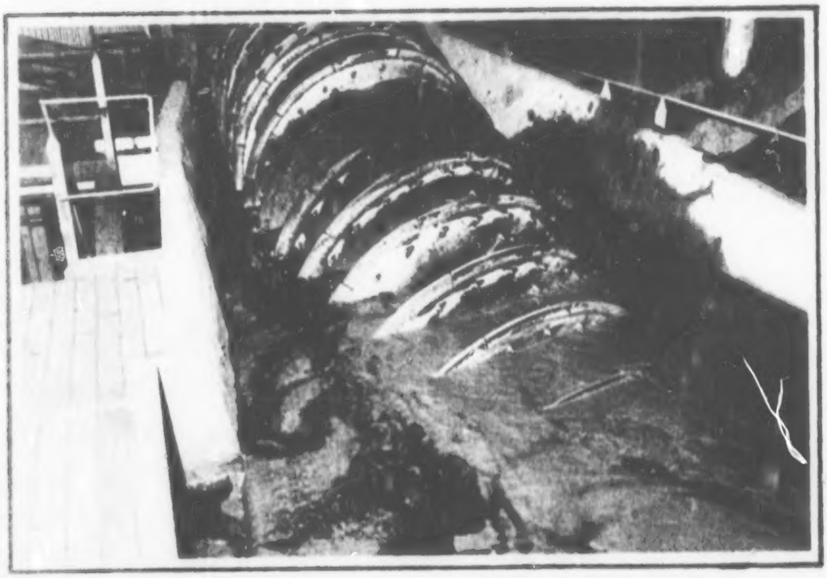

Figure 8-26
A Working Screw Classifier

Screw clasifiers consist of an inclined, round-bottom tank with one or two spirals mounted on a through-shaft parallel to the tank bottom. The spiral structure effects the necessary agitation in the pool and conveys the settled solids up the bottom of the tank to the discharge lip. The slurry is fed into the classifier with a minimum head and at pool level to minimize undesirable agitation. The pool level is maintained by adjusting the height of the overflow weirs. The overflow drops into a collection pipe and is usually routed to a thickener. The underflow may report directly to the refuse belt if sufficiently dewatered or to a secondary dewatering device. The amount of water overflowing the weir determines the size of the separation since the water overflowing the weir varies with the velocity and vice versa. Additionally, the speed of the spirals may have an effect on the size of separation. Speeding up the spirals pulls more material into suspension and increases the agitation thereby effecting a separation at a coarser level.

REFERENCES AND/OR ADDITIONAL READING

Akopov, M.G.; Cherevko, I.E.; Kinareevskiy, V.A.; Miller, E.V., "Investigations in the Area of Counterflow Coal Separation", U.S.S.R. Austrailian Coal Conference

Allis-Chalmers, "Screening Machinery", Engineering Bulletin on Selection of Vibrating Screens

Baker, A.F.; Deurbrouck, A.W., "Hot Surfactant Solutions as Dewatering Aid During Flotation", U.S.A., Australian Coal Conference

Blankenship, Jack B., "New Materials for Slidability Plus Longer Weat", American Mining Congress Coal Convention, Pittsburgh, Pennslyvania, May 1975

Blankenship R.E., "Operational and Environmental Features of Virginia Pocahontas No. 3 Preparation Plant", Mining Congress Journal, April 1973

Blankmeister, W.; Bogenschneider, B.; Kubitza, K.H.; Leininger, D.; Angerstein, L; Kohling, R., "Optimised Dewatering Below 10 MM", Germany, Australian Coal Conferences

Bluck, W.V. & Norton, G., "High Intensity Fine Coal Flotation", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Bioko, V.A. Parinskiy, O.P., "Equipment for Dewatering of Coal", Chapter 5 of "Hydraulic Capability for Underground Mining of Coal", Katalog-Spravochnik, Moscow, 1965 (Translated by Terraspace)

Borts, M.A.; Ismaylova, I.S.; Stepanova, D.I., "A New Granulated Flocculant, Type OKA", Obogashcheniye i Briketirovaniye Uglya #2 1975 (Translated by Terraspace)

Burdon, R.G.; Booth, R.W.; Mishra, S.K., "Factors Influencing the Selection of Processes for the Beneficiation of Fine Coal", Australia, Australian Coal Conference

Capes, C.E.; McIlhinney, A.E.; McKeever, R.E.; Messer, L., "Application of Spherical Agglomeration to Coal Preparation", Australian Coal Conference

Cavallaro, J.A.; Deurbrouck, A.W.; Baker, A.F., "Physical Desulfurization of Coal", Alche Symposium Series, Vol. 70, pp. 114-122

Cavallaro, J.A.; Johnston, M.T.; Deurbrouck, A.W., "Sulfur Reduction Potential of the Coals of the United States", U.S. Bureau of Mines RI 8118

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Charmbury, H.B., "Mineral Preparation Notebook", Pennsylvania State University

Chironis, Nicholas P., "New Clarifier/Thickner Boosts Output of Older Coal Preparation Plant", Coal Age, January 1976

Coal Age, "Coal Preparation and Unit-Train Loading", July 1972

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Coal Age, "Consol Preparation Confirms Coal Quality", October 1972

Coal Age, "Peabody Pioneers in Coal Handling & Preparation", Model Mining Issue, October 1971

Coal Age, "U.S. Steel Coal Preparation", Model Mining Issue, October 1973

Cook, L., "Practical Application of Hydraulic Mining at Rahui Buller Coalfield", Paper 31, Mining Conference, School of Mines & Metallurgy, University of Otago, May 1953

Cooper, Donald K., "Choosing Closed Circuits for Coal Preparation Plants", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Cooper, Donald, "New Vortex Sieve - Works for Quartz Mining", Coal Mining and Processing, September 1975

Culp-Culp, "Advanced Waste Water Treatment", Van Norsten, 1971

Dahlstron, D.A.; Silverblatt, C.E., "Dewatering of Pipeline Coal", U.S.A., Australian Coal Conference

Dahlstrom, D.A.; Silverblatt, Charles, "Production of Low Moisture Content Fine Coal Without Thermal Drying", Mining Congress Journal, December 1973

Daub, Charles H., "The Oneida Plant", Mining Congress Journal, July 1974

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Department of Environmental Resources, "Waste Water Treatment Requirements"; "Industrial Wastes"; "Special Water Pollution Regulations"; "Erosion Control", State of Pennsylvania

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Deurbrouck, A.W.; Hudy, J. Jr., "Performance Characteristics of Coal-Washing Equipment, Dense - Medium Cyclones", U.S. Bureau of Mines Report of Investigations #7673, 1972

Deurbrouck, A.W., "Performance Characteristics of Coal-Washing Equipment, Hydrocyclones", U.S. Bureau of Mines Report of Investigations #7891, 1974

Deurbrouck, A.W., "Steam as a Coal Dewatering Aid During Vacuum Filtration: A Pilot Plant Study", U.S. Department of Interior, Bureau of Mines Report of Investigations #6718, 1966

Deurbrouck, A.W., "Survey of Sulfur Reduction in Appalachian Region Coals by Stage Crushing", U.S. Bureau of Mines Report of Investigations #8282

Deurbrouck, A.W., "Washing Fine-Size Coal in a Dense-Medium Cyclone", U.S. Bureau of Mines Report of Investigations #7982, 1974

Dokunin, A.V.; Onika, D.G., "Hydraulic Underground Mining", Translated for Branch of Bituminous Coal Research, Division of Bituminous Coal, U.S. Bureau of Mines

Dorr-Oliver, Inc., "Merco Centrifugal Separators", Stamford, Connecticut, 1970

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Analysis of Pollution Control Costs", EPA 670/2-74-009

Ellison, William; Heden, Stanley D.; Kominek, Edward G., "System Reliability and Environmental Impact of SO_2 Processes", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Enviro-Clear Co., Inc., "Coal Preparation Plant Clarifier-Thickener", Bulletin C/11/72, New York City

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Fair, Geyer, and Okun, "Water and Waste Water Engineering", Vol. 2, Wiley and Sons, 1968

Flygt Corporation, "Mine Dewatering Submersible Pumps", Brochure, 1975

Fomenko, T.G.; Kondratenko, A.F.; Perlifonov, A.G., "Thickening of Flotation Tailings in a Thickener with a Sludge Packer", UGOL #1, 1973

Foreman, William El; Lucas, J. Richard, "Current Status of Hydrocyclone Technology", Mining Congress Journal, December 1972

Gayle, J.B.; Eddy, W.H., "Effects of Selected Operating Variables on Continuous-Cell Flotation of Coal: A Lab Study", U.S. Bureau of Mines Report of Investigations #5989

Geer, M.R.; Jacobsen, P.S.; Sokasi, M., "Dewatering Coal Flotation Tailing by the Admixture of Crushed Washery Refuse", U.S. Bureau of Mines Report of Investigations #7110

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

Gospodarka, Gornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Gregory, M.J., "Problems Associated with Closing Plant Water Circuits", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Grimm, Bobby M., "Preparation Plant Corrosion Cost", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Gvozdek, G.; Macura, L., "Hydraulic Mining in Some Deep Pits in Czechoslovakia", Translated by National Coal Board (A 1683), Uhli #12, December 1958

Hall, A.W.; Martin, J.W.; Stewart, R.F.; Poston, A.M., "Precision Tests of Neutron Sulfur Meter in Coal Prepartion Plants", U.S. Bureau of Mines Report of Investigations #8038, 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Hand, John W., "Drying of Western Coal", Mining Congress Journal May 1976

Haskins, J. William, "The Economical Advantages of Drying Coal Fines Using Indirect Heat Exchanging", NCA/BCR Coal Conference and Expo II, October 1975

Henderson, G.S.; Andren, A.W.; Harris, W.F.; Reichle, D.E.; Shugart, H.H.; Van Hook, R.I., "Environmental Assessment of SO_2 and Trace Element Emissions from Coal Utilization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Hewitt-Robins, "The Eliptex Dewaterizer", Engineering Bulletin No. 2103.0601X

Hill, Ronald D., "Water Pollution From Coal Mines", Water Pollution Control Association of Pennsylvania, 45th Annual Conference, 1973

Hudy, J., Jr., "Performance Characteristics of Coal-Washing Equipment", U.S. Bureau of Mines Report of Investigations #7154, July 1968

Hulett, L.D.; Carter, J.A.; Cook, K.D.; Emery, J.F.; Klein, D.H.; Lyon, W.S.; Nyssen, G.A.; Fulkerson, W.; Bolton, N.E., "Trace Element Measurements at the Coal-Fired Allen Steam Plant--Particle Characterization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky 1974

Humboldt-Wedag, "Manufacturers Brochures", Cologne, Germany

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Provence Coalfield", France, Australian Coal Conference

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jacobsen, P.S.; Kokaski, M.; Geer, M.R., "Performance of a Screw-Type, Classifier Cyclone Combination", U.S. Bureau of Mines Report of Investigations #6109

Jeffrey Mining Machine Co., "Jeffrey Mining Machine Company: Manufacturers Information", Columbus, Ohio

Jenkinson, D.C., "Some New Coal Preparation Developments in the United Kingdom", National Coal Board Bulletin M4-B148

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Johnson Divison, UOP Company, "Brochure - 1975"

Jonakin, J., "Solving the SO_2 Problem--Where We Stand with Application and Costs", Coal Age, May 1975

Kalb, G. William, "The Attainment of Particulate Emission Standards at Fluidized-Bed Thermal Coal Dryers", American Mining Congress Coal Show Detroit, Michigan, May 1976

Kent, James A. (Editor), "Riegel's Handbook of Industrial Chemistry (7th Ed.)", Van Nostrand Reinhild Publishing Company, New York, 1974

Kester, W.M., "Magnetic Demineralization of Pulverized Coal"

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

Kodentsov, A.A.; Kurkin, V.F.; Krasnoyarskiy, L.S.; Papkov, M.N., "Dewatering of Coal and Rock, Clarification of Waste Water During Driving by Hydromechanization", Ugol Ukrainy #11 (Translated by Terraspace)

Kollodiy, K.K.; Borodulin, V.A.; Nazarov, P.G., "Processing of Coal Mined by the Hydraulic Method", Ugol #9, 1974 (translated by Terraspace)

Korol, Dionizy, "Influence of Hydraulic Getting on Mechanical Coal Preparation", Przeglad Gorniczy, Year 12 #12, December 1956 (National Coal Board Translation Section)

Lamella (Sala of Sweden), "Theory and Design of the Lamella Gravity Settler", Technical Bulletin #105, May 1975

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

LLewellyn, Robert L., "Coal Preparation", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York, 1968

Lotz, Charles W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Lowman, Stephen G., "Westmoreland Coal's Bullitt Plant Upgrades Steam Coal Quality", Coal Age, 1973

Lowry, H.H. (Editor), "Chemistry of Coal Utilization", John Wiley & Sons, Inc., New York, New York, 1963

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Lovell, Harold L., "Sulfur Reduction Technologies in Coals by Mechanical Beneficiation (3d Draft)", Commerce Technical Advisory Board Panel on SO_2 Control Technologies, March 1975

Manwaring, L.G., "Coarse Coal Cleaning at Monterey No. 1 Preparation Plant", Mining Congress Journal, March 1972

Markley, R.W.; Cavallaro, J.A., "Efficiency in Cleaning Fine Coal by Froth Flotation--A Cell by Cell Pilot Plant Evaluation", Mining Congress Journal, June 1974

Mathur, S.P., "Hydraulic Mining of Coal", Journal of Mines, Metals and Fuels, May 1972

McNally-Pittsburg Manufacturing Corporation, "Coal Cleaning Plant Prototype Plant Design Drawings", Department of Health, Education and Welfare Contract 22-68-59

McNally-Pittsburg Manufacturing Corporation, "Coal Preparation Manual #572", Extensive Analysis on McNally Pittsburg Coal Cleaning Technology

Mengelers, J.; Absil, J.H., "Cleaning Coal to Zero in Heavy Medium Cyclones", Coal Mining and Processing, May 1976

Metcalf & Eddy Inc., "Waste Water Engineering, Collection-Treatment-Disposal", McGraw-Hill

Miller, F.; Wilson, E.B., "Coal Dewatering - Some Technical and Economic Considerations", American Mining Congress Coal Convention, May 5-8, 1974

Morris, George J., "Reclaiming Coal from Refuse Ponds", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Moss, E.A.; kens, D.J., Jr., "Dewatering of Mine Drainage Sludge", EPA R2-73-169, February 1973

National Coal Association, "First Symposium on Mine & Preparation Plant Refuse Disposal", Coal and the Environment Technical Conference, October 1974

National Coal Board, "Exploratory Trails in Hydraulic Mining at Trelewis Drift Mine", September 1961

REFERENCES AND/OR ADDITIONAL READING
(Continued)

National Coal Board, "Hydraulic Transport of Coal at Woodend Colliery", September 1961

Nirtsiyev, "Hydraulic Extraction of Coal in the Donetz Basin Izdatel 'Stvo "NEDRA", Moscow 1969 (Translated by Terraspace)

Nunenkamp, David C., "Survey of Coal Preparation Techniques for Hydraulically Mined Coal", Published for Terraspace Inc., July 1976

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

Pritchard, David T., "Closed Circuit Preparation Plants and Silt Ponds", Mining Congress Journal, November 1974

Protsenko, I.A., "The Technology of Beneficiation and Dewatering of Coal Mined by the Hydraulic Method", Questions Regarding the Hydraulic Production of Coal, Trudy VNIIGidrougol, Vol. XI, 1967 (Translated by Terraspace)

R.M., Wilson Company, Inc., "Mine Productivity Systems and Equipment", Catalog #288-P

R.M. Wilson Company, Inc., "Vor-Siv Model 2000", Wheeling, West Virginia, 1974

Roberts & Schaefer Company, "Manufacturers Information Booklets", Chicago, Illinois

Roberts & Schaefer Company, "Design & Cost Analysis Study for Prototype Coal Cleaning Plant", August 1969

Roberts & Schaefer Company, "Material Handling and Processing Facilities for the Mining Industry", 1974

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant", January 1973

Sal'nikov, V.R., "Experience and Outlook Regarding the Application of Hydromechanization of Steep Seams in the Kuzbass", UGOL #7, 1973

Sands, P.F.; Sokaski, M; Geer, M.R., "Performance of the Hydrocyclone As a Fine Coal Cleaner", U.S. Bureau of Mines Report of Investigations #7067, January 1968

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Sarkar, G.G.; Konar, B.B.; Sakha, S.; Sinha, A.K., "Demineralization of Coal by Oil-Agglomeration", Part I: Studies on the Applicability of the Oil-Agglomeration Technique to Various Coal Benefication Problems, India, Australian Coal Conference

Schuhmann, Reinhardt, Jr., "Metallurgical Engineering, Vol. I, Engineering Principle", Addison-Westey Publishing Company, Inc., Reading, Massachusetts, 1952, p. 84

Skinderowicz, F., "Typical Technical Solutions of a Loading Point During Gravity Hydraulic Transportation of Coal", Waidomosci Gornicza, Vol. 10 #3, 1959

Sokaski, M; Sands, P.F.; Geer, M.R., "Use of a Sieve Bend and a Scalping Deck With a Vibrating Screen in Dewatering and Draining Dense Medium From Fine Coal", U.S. Bureau of Mines Report of Investigations #6311

Stefanko, Robert; Ramani, R.V.; Chopra, Ish Kumar, "The Influence of Mining Techniques on Size Consist and Washability Characteristics of Coal", National Technical Information Service, Springfield, Virginia, August 1973

Stoev, St.; Krasteva, K., "Coal Preparation by Reverse Stratification", Bulgaria, Australian Coal Conference

Terchick, A.A.; King, D.T.; Anderson, J.C., "Application and Utilization of the Enviro-Clear Thickener in a U.S. Steel Coal Preparation Plant", Transactions of the SME, Volume 258, June 1975

Terry Richard L., "Minerals Concentration by Wet Tabling", Minerals Processing, July/August 1974

Tieman, John W., "Chemistry of Coal", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York 1968

Tyler, C.E., "Testing Sieves & Their Uses", Combustion Engineering, Inc. Handbook #53, 1973 Edition

U.S.S.R., "Intensification of Coal Slurries Treatment and Dewatering Processes", Australian Coal Conferences

Verschuur, E.; Davis, G.R., "The Shell Pelletizing Separator: Key to a Novel Process for Dewatering and De-Ashing Slurries of Coal Fines", Holland, Australian Coal Conference

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Warnke, W.E., "Latest Progress in Sulfur, Moisture and Ash Reduction Coal Preparation Technology", American Mining Congress Coal Convention, Detroit, Michigan, May 1976

Wei-Tseng Peng, "The Jet-Cyclo Flotation Cell", The People's Republic of China, Australian Coal Conference

Wemco Division, "Manufacturer's Catalog", Envirotech Corporation, Sacramento, California, 1974

Yencey, J.F.: Geer, M.R., "Behavior of Clays Associated with Low-Rank Coals in Coal-Cleaning Processes", U.S. Bureau of Mines Report of Investigations #5961

Yancey, J.F., "Determination of Shapes of Particles in Coal and Their Influence on Treatment of Coal by Tables", AIME Translation, 94

Yusa, M.; Suzuki, H.; Tanaka, S.; Igarashi, C., "Slude Treatment Using A New Dehydrator", Japan, Australian Coal Conference

9. CLEAN COAL STORAGE AND HANDLING

9.1 OVERVIEW

The larger handling and producing systems in use today are dependent on an assured supply of coal of specific quantities being available at a specific time. It is no longer feasible to load clean coal at the rate of production of the coal cleaning plant. Since the inception of the unit train, clean coal storage, in some form, has become an economic necessity. Several of the more important reasons for storing of clean coal are:

- to quickly and economically load unit trains, barges and other intermittent bulk transport conveyances,
- to facilitate the attainment of maximum product uniformity of shipped clean coal,
- to keep clean coal on hand for domestic and truck trades and
- to eliminate the dependency on preparation plant production.

The relationship of the clean coal storage module to the preparation plant is highlighted in Figure 9-1.

The reasons for clean coal storage are clear. There are, however, numerous adverse factors to be considered. Among them are:

- the oxidation and spontaneous combustion of the coal,

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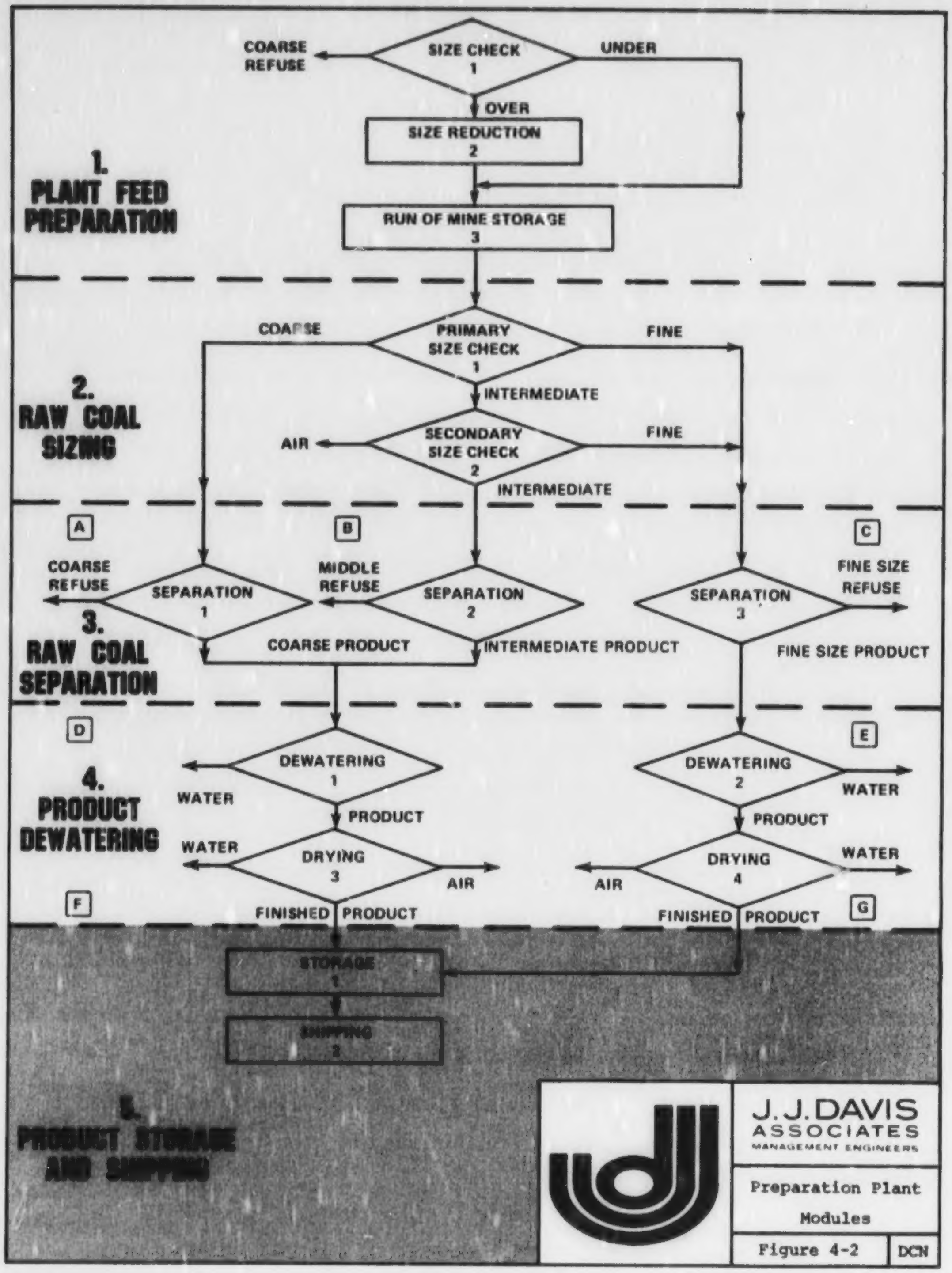


Preparation Plant Modules

Figure 4-2

- the alteration of the physical properties of coal while being stored,
- the loss of product due to wind and erosion, and degradation due to rehandling and
- the increased capital cost of handling and storage facilities.

The affinity of a coal stockpile to spontaneously heat is very difficult to assess. It is, of course, directly dependent on the amount of oxidation which takes place, but oxidation, in turn, is dependent on many other factors such as the rank of the coal (the higher the rank, the less tendency to oxidize), the size consist of the coal in the pile, the method by which it is stacked, the temperature at which the coal is piled, external heat additions, the amount and size of pyrite present, moisture content, ventilation conditions in the pile, storage time and the presence of foreign materials. Because each of these variables is important, the spontaneous combustion of a coal stockpile may take place under a certain set of environmental conditions at one location, while not taking place at another site with slightly altered conditions or different coal characteristics.

Coal weathers as it oxidizes in storage. Weathering or "slacking" as it is sometimes referred to, occurs more readily in low-rank coals than high-rank coals. It is defined as the disintegration of the coal on exposure to the weather, particularly when alternately wetted and dried or subjected to hot sunshine. This phenomenon is detrimental from the utilization standpoint, both in decreases of heating value and loss of coking properties of the coal. This factor has substantial bearing on the selection of storage facilities at the plant, i.e., whether they should be open or closed, although it has been found that the oxidation rate decreases with time and generally the loss in heating value is not as great as once it was thought to be.

Another consideration as to storage type is the potential loss of coal product through windage (dust loss) and erosion. This consideration is dependent on the geographical location of the proposed storage site and may be of significant importance.

The impact of any of the above factors may be greatly reduced by using closed storage facilities such as bins or silos. Closed storage systems are high capital cost items and their use is restricted by economics. However, the time of storage factor is of great importance in determining the type of storage. It has been found that short-term storage, if done properly, can usually be of the open type while a great deal more consideration must be given to coal which is to be stored for longer periods of time. The optimum storage of clean coal lies not only in the selection of the adequate type, but also in the proper construction and maintenance of the storage facility.

9.2 CLEAN COAL STORAGE

The reasons for storing clean coal have been presented previously; and the methodologies of clean coal storage will now be discussed. As a minimum, ½ hour of rated plant capacity of clean coal is suggested as the minimum storage necessary to provide a reserve against production interruptions which would directly impact efficient transport of the clean coal. It is, however, more common to store larger quantities of clean coal either in bins or silos or in ground storage facilities. Bins and silos may be singular, monolithic storage areas ranging in capacity from 1,000 tons to 15,000 tons per unit. It is common to find multiple clusters of bins or silos at a storage facility. The cluster storage approach provides flexibility, better reliability and the advantage of being able to blend the final product mix. Ground storage capacity, on the other hand, ranges from a low of about 5,000 tons to a high of 30,000 tons and oftentimes more. Storage facilities appear in a number of shapes with a multitude of contributing variables. The use of large singular silos is becoming more and more popular with increased unit train loading, and as more economical methods of constructing the concrete silos are developed, space-saving considerations have also added impetus to the trend toward this type of storage.

The industry trend is toward increased use of the unit train concept for removing clean coal from the storage area. Therefore, plant installations must have storage facilities amenable to this system. The criteria used in the decision as to which type of storage will be used at a particular site include such factors as:

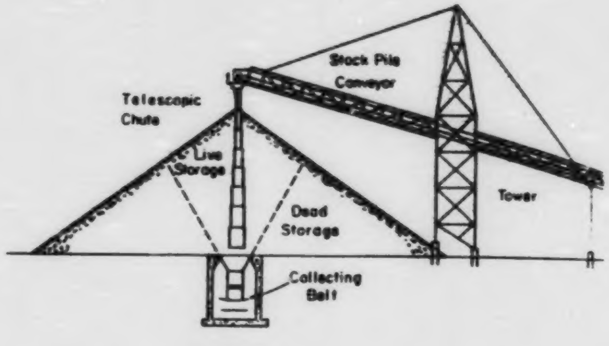
- Whether or not the coal has been thermally dried. There is a natural reluctance to put the coal in open storage if it has been thermally dried. If the market calls for a low moisture coal, a closed storage bin or silo is desirable.
- Is dust control critical? If so, a closed bin or silo is desirable. If dust control is desirable but not critical, a standpipe or telescoping tube in an open stockpile is adequate.
- Is the weather such that coal would tend to freeze in open storage or in rail cars? A closed bin or silo is often better.
- What initial capital is available for investment in storage facilities?

9.2.1 Open Storage for Clean Coal

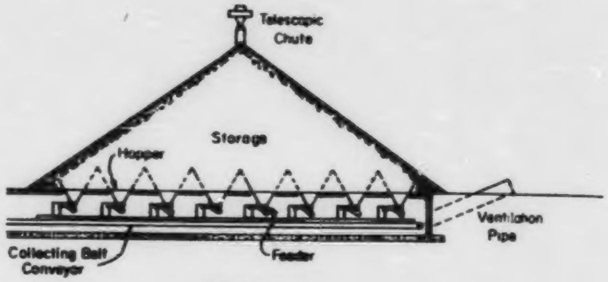
Open storage, often called ground storage, is the least expensive of all storage methods. It simply consists of storing the clean coal directly on the ground or in shallow pits in any of several configurations dependent on the handling system being used.

The most common of the open storage configurations is the conical-shaped pile. As displayed in Figure 9-2, this configuration is used in over 60% of coal operations employing unit train loading. A conical storage pile may have a flat bottom using either coal in the dead storage area or earth filled into a doughnut shape to serve as the dead area. The majority of operators employing conical pile storage use dead coal as a satisfactory enclosure. The dead coal also constitutes a reserve for the loader. Instead of coal, fabricated enclosures may occasionally be employed. Earth embankments are used in a number of installations. These embankments may completely enclose the storage pile, or if terrain permits, may be left open at strategic points for bulldozing or other methods of moving to create additional storage. The slope of the enclosure wall is usually 40 to 45 degrees or approximately the angle of repose of the coal being handled. Additionally, the storage area may be cut into hillsides using the natural rock as a partial enclosure.

Concial stockpiles may have varying capacities depending on the height of the pile and the angle of repose of the coal. The major disadvantage of this type of storage is the relatively low ratio of live to dead storage. Assuming a 45° angle of repose, only about 1/5 of the coal in a conical pile is live coal if the only recovery opening is in the center of the pile. To avoid this, several openings may be used extending across the



ELEVATION



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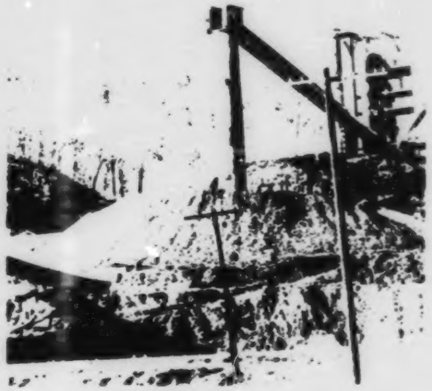


J. J. DAVIS
ASSOCIATES
MANAGEMENT ENGINEERS

Conical Shaped
Stockpile

Figure 9-2

DWG

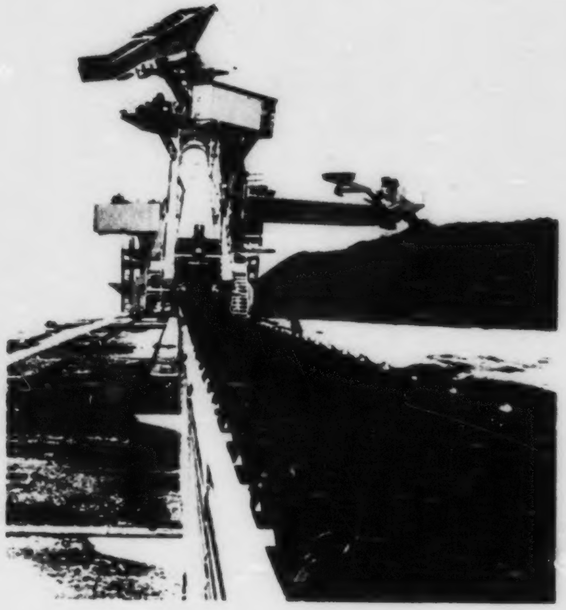
diameter of the pile. This may increase the live coal ratio to about 55%.

Buildup of the conical pile usually begins on a prepared, compacted surface. A fixed, cantilevered, stacker conveyor delivers coal to the pile and is usually equipped with a telescopic chute or fixed standpipe with multi-level openings to restrict dust. The pile is situated over the reclaiming tunnel and necessary feeders which feed onto a reclaiming conveyor which, in turn, may deliver the product to a loadout hopper over the track or tracks for unit train loading.

Another open storage method consists of a long wedge-shaped pile which is capable of storing from 40,000 to 100,000 tons of clean coal. These wedge-shaped piles are built with a traveling stacker that operates with a belt conveyor running parallel to the pile. The conveyor is generally elevated to about half the height of the pile, either on an earth fill or on a steel structure. The pile is built as the movable tripper slowly traverses the length of the pile. The stacker may have either a fixed or a hinged boom, the latter serving to practically eliminate dust problems.

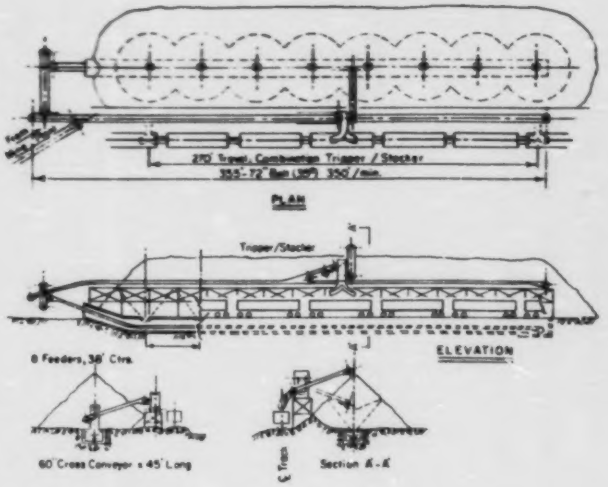
Wedge-shaped piles can either be reclaimed by using an under-the-pile conveyor system similar to that previously described for a conical pile, or a stacker/reclaimer system may be employed for both functions. Both systems are shown in Figure 9-3. The stacker/reclaimer system is a more recent innovation, adapted from strip mining technology and initially used at power plants, but now appearing at preparation plants as well. It is quite a versatile storage method which allows storage on both sides of the conveyor track.

Stacker-Reclaimer



Source: McNally-Pittsburg

Underground Conveyor Reclaim System


270' Travel, Combination Tripper / Stacker
355'-72" Belt (30°) 350'/min.
PLAN
Tripper/Stacker
ELEVATION
8 Feeders, 38' Ctrs.
60' Cross Conveyor x 45' Long
℄ Tripper
Section A-A

J.J.DAVIS
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MANAGEMENT ENGINEERS

Wedge-shaped
Stockpile

Figure 9-3 DRW

A final type of open storage, frequently found at power plants and finding increased application in preparation plants is the kidney-shaped stockpile shown in Figure 9-4.

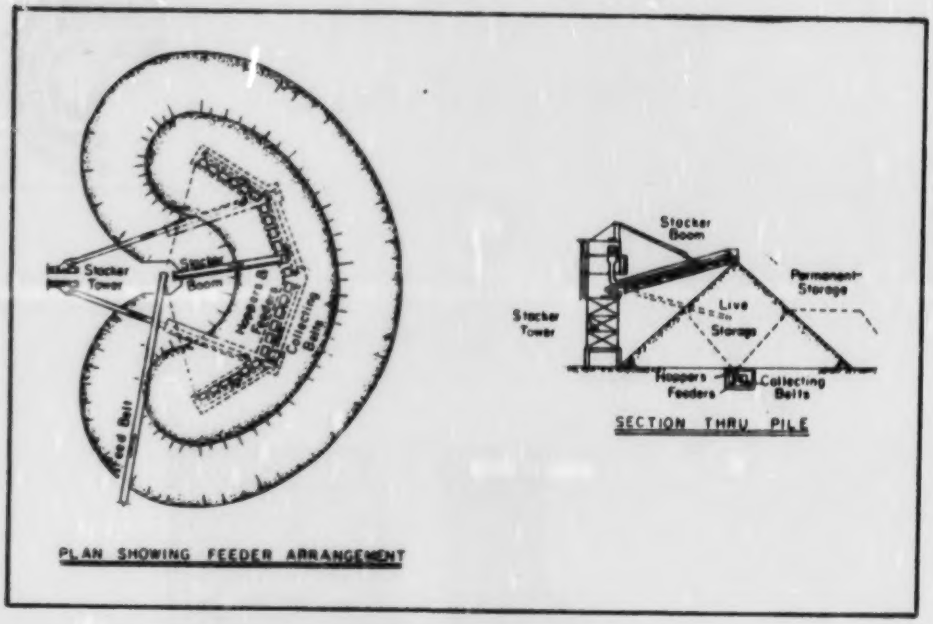


Figure 9-4
Kidney-Shaped Stockpile
Source: Coal Preparation, op.cit., p. 15-18

The kidney-shaped stockpile is formed by a stationary radial stacker with a boom that rotates through an arc and which raises and lowers as necessary. The stacker may be either ground or tower mounted. This type of storage has the major advantage of being able to stock a large supply of clean coal using a minimum of space and handling. Offsetting this advantage, however, are the disadvantages of high capital investment, high maintenance costs and the need for a more complex reclaiming arrangement to achieve maximum efficiency.

9.2.2 Closed Storage for Clean Coal

For various reasons, such as to prevent freezing, it may be desirable to use enclosed storage facilities. When such a situation exists, bins or silos are generally used. These storage vessels are predominantly circular in shape and may be made of either steel or concrete. An example of a facility employing a combination of both the steel and concrete type silos is shown in Figure 9-5.

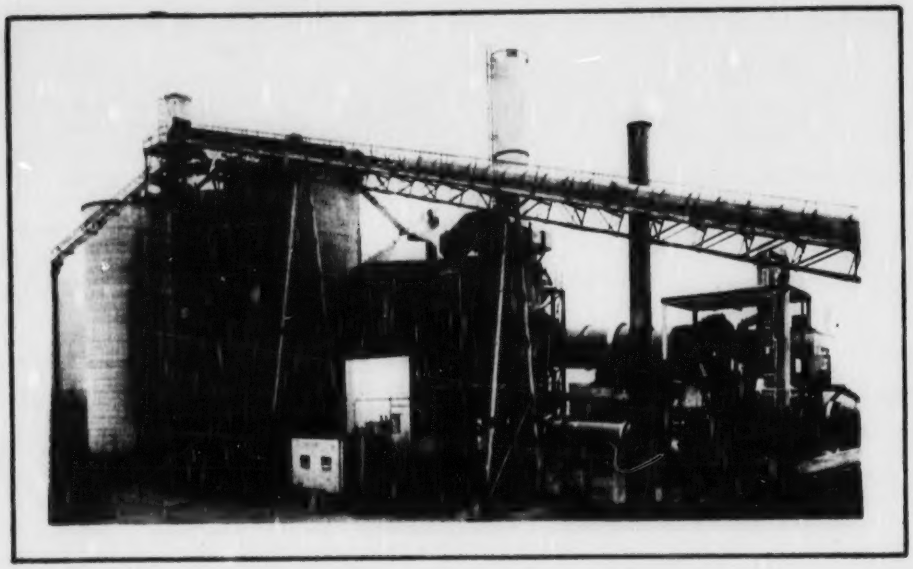


Figure 9-5
Steel and Concrete Storage Silos

Source: FMC Mining Equipment

Both the steel and concrete silos have arrangements to withdraw coal through the bottom of the silos. These may be either in the form of a surface conveyor or a buried conveyor arrangement. A sloped steel plate or treated earth fill in the bottom of the silos assures total recovery of the coal by using gravity. Larger diameter silos or bins 100 feet in diameter, for example, generally have more than one feeder chute at the bottom as shown in Figure 9-6.

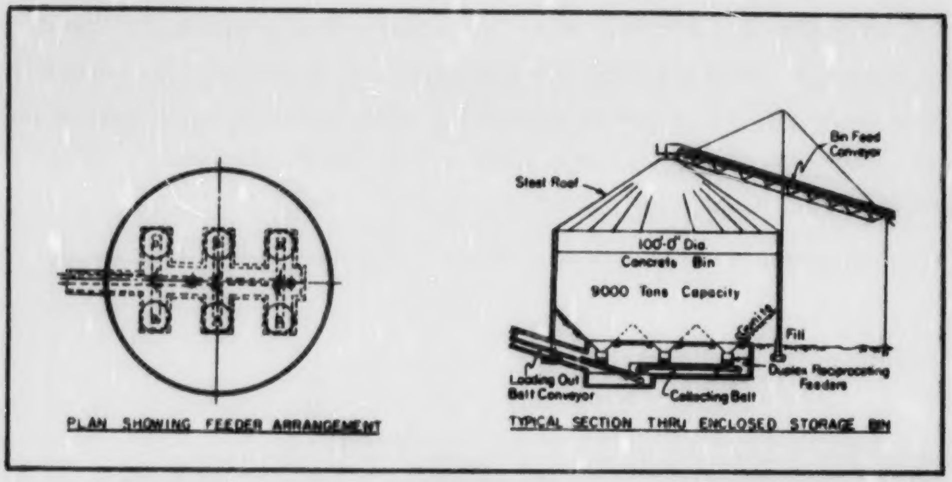

PLAN SHOWING FEEDER ARRANGEMENT
Steel Roof
Bin Feed Conveyor
100'-0" Dia.
Concrete Bin
9000 Tons Capacity
Fill
Loading Out Belt Conveyor
Collecting Belt
Duplex Reciprocating Feeders
TYPICAL SECTION THRU ENCLOSED STORAGE BIN

Figure 9-6
Monolithic Concrete Bin

The past trend in the industry was towards a cluster of smaller (1,500 to 2,000 tons per silo) concrete silos. These were generally of the precast stave-type silos, were less expensive than the larger monolithic bin types and provided considerable flexibility in blending the final product. Some recently built unit train facilities employ as many as five or more silos at a single site. However, the current trend is to a single larger storage silo as depicted in Figure 9-6.

Though occasionally used for clean coal storage, the rectangular-type bin has found only limited application. However, these bins are used for flood-loading or choke loading unit train cars from other types of storage facilities. This type of bin is commonly built at the same capacity as the hopper cars being loaded. They do vary in capacity, but the majority of rectangular bins are under 200 ton capacity. A typical installation is shown in Figure 9-7.

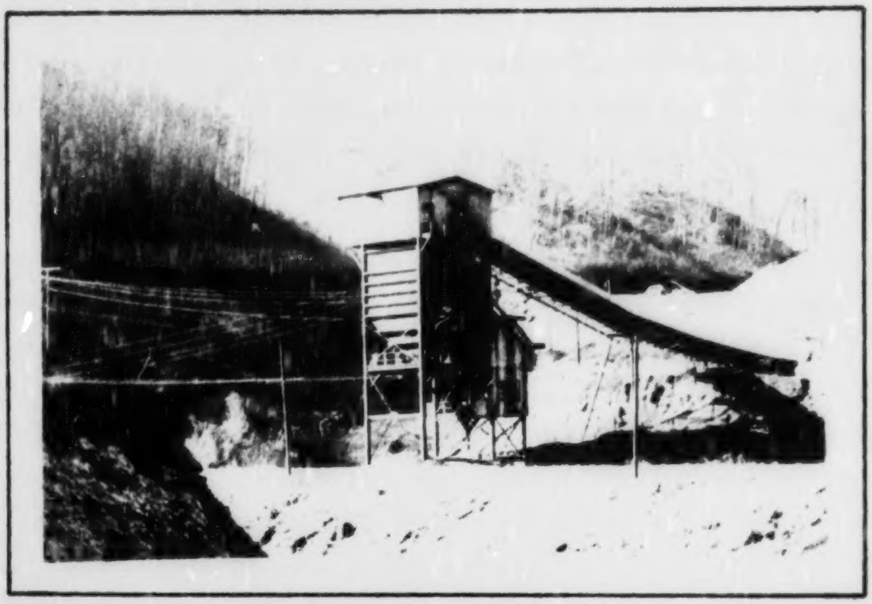


Figure 9-7
Flood Loading From Steel Surge Bin

In contrast to open storage facilities, enclosed storage facilities practically eliminate blowing dust and windage losses and protect the clean coal from the elements. Additionally, these facilities provide nearly 100% live storage of clean coal and eliminate all the pollution problems associated with coal storage.

9.3 CLEAN COAL HANDLING

Most coal handling systems incorporate a storage arrangement to provide several thousand tons live storage. This is critical when systems such as the unit train are being used which require a rather rapid loadout. The development of the unit train with its attendant economics, more than any other factor, has contributed to the widespread construction of storage and high-speed loading facilities. As this is the most prevalent of today's systems, primary emphasis will be placed on it during the following discussions. Other systems employ waterborne loading, as in the use of barge haulage, and slurry pipelines, although this system is not practiced widely as yet.

9.3.1 Unit Train Loading

The unit train has been defined as a complete train of conventional size and equipment operating on a regularly scheduled cycle movement, with dedicated or private cars and assigned locomotives, between a single origin and a single destination. The typical unit train loading facility in the United States has a load-out capacity of 3,000 to 3,500 tons per hour, with a maximum to date of 11,000 tons per hour at one installation. Though the railroads handle larger trains over the road, the largest usually placed for loading at mines is around 10,000 tons, with the smallest ranging from 3,000 to 3,500 tons. The number of cars using a single track loading ranges from 30 or 40 to over 100 cars. Specially designed cars for unit train service are being used in increasing numbers. The size of special experimental cars has reached 240 tons.

Single track loading is the general rule. However, two loading tracks are used in some layouts with a maximum ranging up to six. With few exceptions, car loading is done from an overtrack surge hopper ranging in capacity from 85 to 300 tons. Flood loading rates may exceed 3,000 tons per hour. Where more than one silo or row pile is operated, each has its own complement of feeders--in the case of silos, usually 6 to 8 feeders are strategically located across the bottom. In one installation located over a train sized tunnel, only one chute per cone is required to load at the rate of 6,000 tons per hour.

Another installation, shown in Figure 9-8, utilizes two adjacent silos with a single pass-through tunnel for loading a 94-car unit train. The cars are 100 tons capacity and the entire load-out can be accomplished in under two hours. The locomotive first backs the empty cars through the tunnel, and when the direction is reversed, loading commences continuously until the entire train has been loaded. An operator controls the feed chute, which serves to contour the load as well as control dust and constant loading conditions.

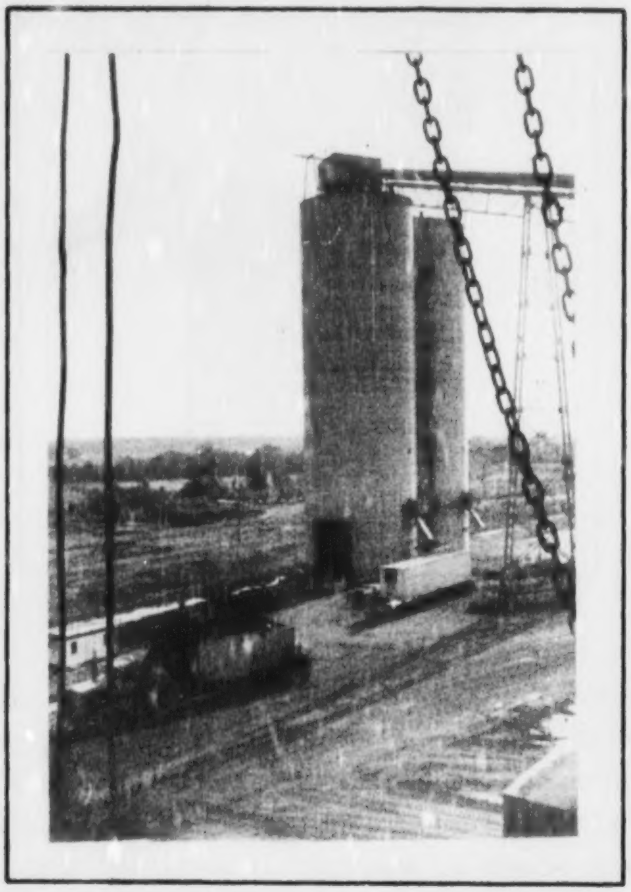


Figure 9-8
Two-Silo Unit Train Loading System

There are basically three approaches used in the loading of unit trains: locomotive, car haul and tripper conveyor. The first system is the fastest, whereby conventional locomotives move the cars in one pass on one or more parallel tracks. The surge bin used has a capacity of around 1 1/2 times that of the railroad cars. As the cars move under the load point, the loading chute or chutes can be lowered to permit flood loading and contour control.

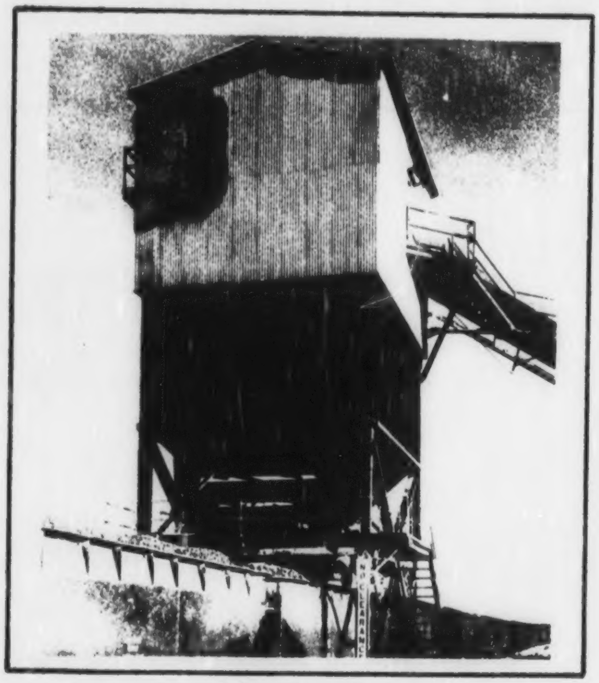


Figure 9-9
Minimal Unit Train Loading Facility

The car haul system consists of a reversible double-drum hoist with haulage ropes leading to dummy cars on the end of both strings of cars. One string of cars is moved in one direction and loaded while the other string is simultaneously moved in the opposite direction. Upon completion of car loading in one direction, the hoist is reversed and loading commences in the opposite direction.

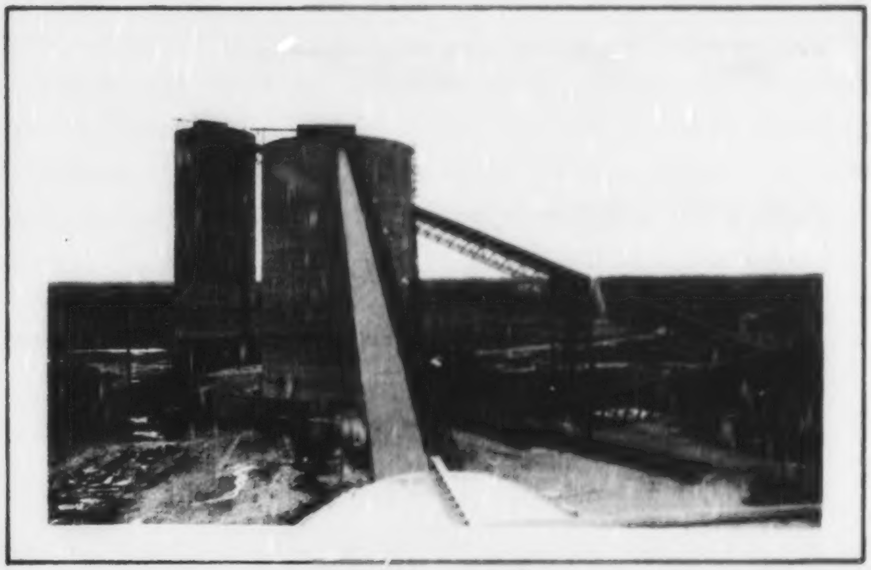


Figure 9-10
Maximized Unit Train Loading Facility

Loading cars are normally removed and replaced with empties before the car haul begins in opposite directions to reduce the load on the hoist.

Figure 9-11
Car Haul System of Unit Train Loading

Source: McNally-Pittsburg

The third system is one in which the train remains stationary while being loaded by a movable tripper running parallel to the train. Two strings of cars are positioned, one on each side of the tripper. As the tripper completes loading of one string it reverses the direction and begins loading the other string. Meanwhile, the loaded string of cars is removed and replaced with an empty set.

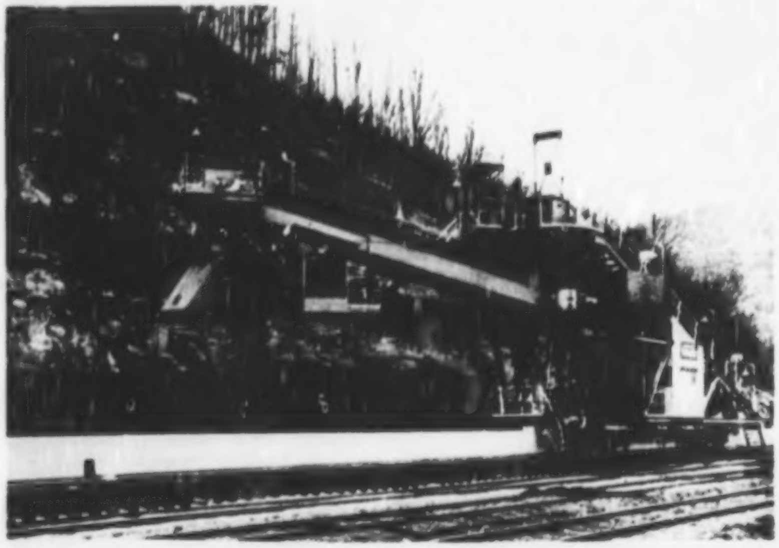


Figure 9-12
Unit Train Loading With Movable Tripper
Source: McNally-Pittsburg

In a variation of unit train loading, a stacker/reclaimer can be used to load directly from an open storage pile onto a conveyor which is discharged by the use of a movable tripper. A stacker/reclaimer is shown in operation in Figure 9-3.

A particularly efficient operation at the York Canyon Mine near Raton, New Mexico, was built by McNally-Pittsburg

(Figure 9-13). This system loads 84 gondolas in less than two hours. As the gondolas pass through a tunnel underneath the conical coal stockpile, a hydraulically activated gate and chute load the 100 ton cars. The system is estimated to haul 700,000 tons of bituminous coal per year.

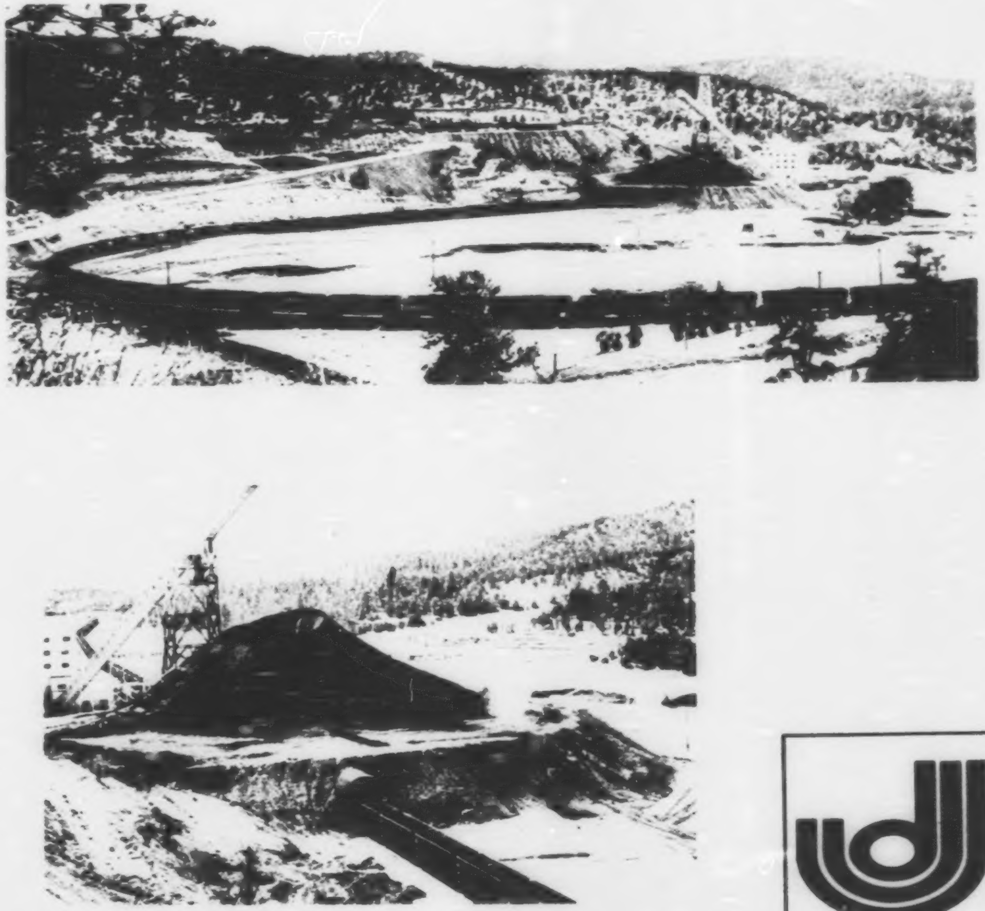
9.3.2 Barge Loading

As with unit train loading, flood loading of barges involves both silo and ground storage of the coal, usually in the higher ranges of capacity. For example, 14,000 tons for a single silo and 75,000 tons for a ground storage facility, fed by a traveling stacker. Loading rates of 5,000 tph will permit loading of 15 barges in less than 5 hours.

Barge loading has enjoyed an increase in popularity during recent years for several reasons. This is a low-cost shipping method which is becoming more efficient as the waterway systems and equipment are improved. There are numerous varieties of loading systems employed for barge loading, generally paralleling technologies used for unit train loading. For example, Figure 9-14 shows barge loading using a movable tripper with telescoping chute to control dust loss and load contour characteristics.

Five basic types of barge loading plants are encountered as follows:

- A simple dock from which trucks dump directly into the barge.
- A stationary-chute type which works well where river fluctuations are not too great and banks are steep.
- An elevating-boom type where the barges moved back and forth in the river beneath. The elevating boom allows more loading time if river



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Unit Train Being Loaded Out In A Western Mine

Figure 9-13 DRW

elevations change greatly. This type is advantageous where the river bank is a considerable distance from the loading channel since the elevating boom and conveyor belt can be combined to span the shallow water area adjacent to the river bank.

- Floating-barge type, with the loading boom mounted on a floating, or spar, barge and pivoted for easier loading. This unit requires a steep bank or fill to permit retraction and extension of the main conveyor with changes in the water level.

- A tripper-conveyor type, in which the barges are stationary and the loading chute moves back and forth to load thus eliminating barge shi[illegible]ing during loading.

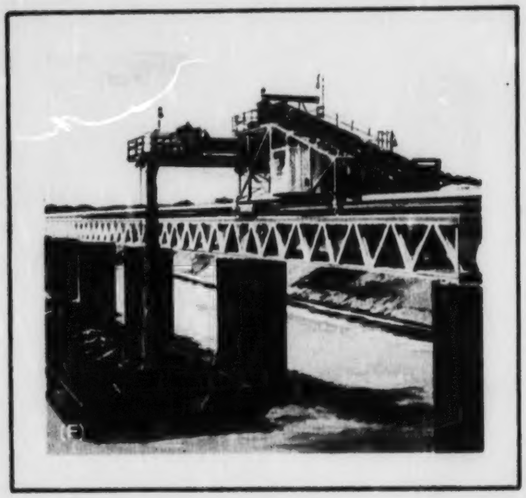

Figure 9-14
Barge Loading with Movable Tripper

Source: McNally-Pittsburg

Figure 9-15 depicts three different barge loading facilities. The first, a dock loading facility, the second, an elevated trans-waterway facility, and the third, a unit-barge facility.

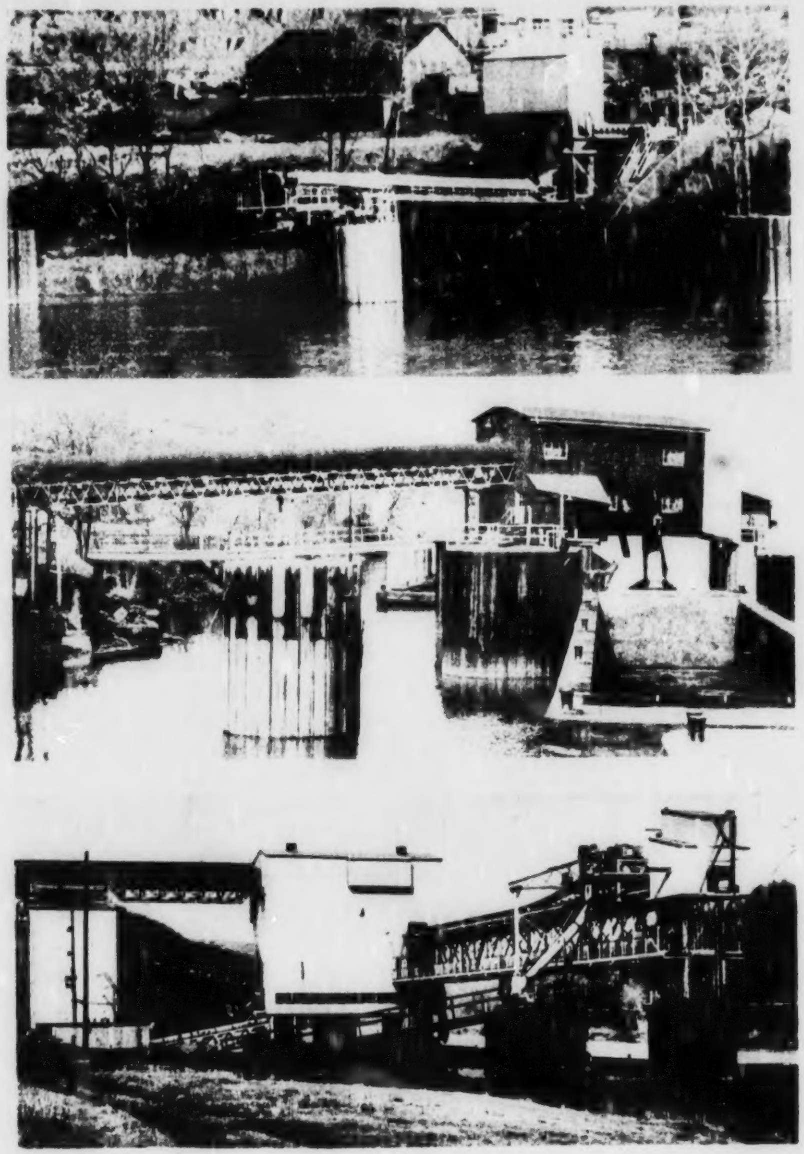

Figure 9-15
Various Barge Loading Facilities

9.3.3 Slurry Pipeline

Coal slurry pipelines have been proposed as a low cost and environmentally sound method of moving coal. Unless the length of haul exceeds 500 miles, the problems of water supply, pipeline right of way, dewatering and costs of facilities cannot be justified. However, one slurry pipeline is in continuous successful use in Arizona. On the other hand, if coal is desulfurized by some physical coal preparation technique resulting in a finely ground wet product, a pipeline may be a feasible choice for transporting the coal.

REFERENCES AND/OR ADDITIONAL READING

Bechtel, Inc., "Coal Slurry Pipeline--An Environmental Answer", San Francisco, California

Blankenship, R.E., "Operational and Environmental Features of Virginia Pocahontas No. 3 Preparation Plant", Mining Congress Journal, April 1973

Charmbury, H.B., "Mineral Preparation Notebook", Pennsylvania State University

Coal Age, "Coal Preparation and Unit-Train Loading", July 1972

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Coal Age, "Consol Preparation Confirms Coal Quality", October 1972

Coal Age, "Peabody Pioneers in Coal Handling & Preparation", Model Mining Issue, October, 1971

Coal Age, "Rail Transport Dominates...", Mid-May 1975

Coal Age, "U.S. Steel Coal Preparation", Model Mining Issue, October 1973

Coal Age, "Using Waterways to Ship Coal", July 1974

Consolidation Coal Company, "Conveying a Slurry Through a Pipeline", British Patent #861-537, February 1961

Cook, L., "Practical Application of Hydraulic Mining at Rahui Buller Coalfield", Paper 31, Mining Conference, School of Mines & Metallurgy, University of Otago, May 1953

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Dahlstron, D.A.,; Silverblatt, C.E.,"Dewatering of Pipeline Coal", U.S.A., Australian Coal Conference

Daub, Charles H., "The Oneida Plant", Mining Congress Journal, July 1974

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Dokunin, A.V.; Onika, D.G., "Hydraulic Underground Mining", Translated for Branch of Bituminous Coal Research, Division of Bituminous Coal, U.S. Bureau of Mines

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

Gospodarka, Gornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Gvozdek, G.; Macura, L., "Hydraulic Mining in Some Deep Pits in Czechoslovaki", Translated by National Coal Board (A 1683), Uhli #12, December 1958

Humboldt-Wedag, "Manufacturers Brochures", Cologne, Germany

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Provence Coalfield", France, Australian Coal Conference

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jeffrey Mining Machine Co., "Jeffrey Mining Machine Company: Manufacturers Information", Columbus, Ohio

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

Korol, Dionizy, "Influence of Hydraulic Getting on Mechanical Coal Preparation", Przeglad Gorniczy, Year 12 #12, December 1956 (National Coal Board Translation Section)

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Llewellyn, Robert L., "Coal Preparation", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York, 1968

Lotz, Charles W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Martinka, Paul D.; Blair, A. Ross, "Western Coal Transportation - A Challenge", American Mining Congress Convention, October 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Roberts & Schaefer Company, "Manufacturers Information Booklets", Chicago, Illinois

Tieman, John W., "Chemistry of Coal", Elements of Practical Coal Mining, Seeley W. Mudd Series, American Institute of Mining, Metallurgical and Petroleum Engineering, Inc., New York 1968

Wemco Division, "Manufacturer's Catalog", Envirotech Corporation, Sacramento, California, 1974

10. REFUSE HANDLING

10.1 OVERVIEW

Coarse refuse material is transported by a variety of materials handling systems, singly and in combination with others. A listing of the systems includes:

- aerial tram,
- conveyors, both belt and metal pan,
- trucks, both end and bottom dump,
- side dump mine cars,
- scrapers and
- bulldozers.

As with mine development refuse, the majority of operators in the past have transported and deposited coarse refuse under relatively uncontrolled conditions. Little or no attention was given to effective compaction or other density control methods. Water content depended upon that which came from the plant, along with additions or removals from the dump surface in conjunction with current weather conditions. Placement, drainage and stability have usually been a matter of circumstance.

When controlled placement of coarse refuse is in effect, however, the materials handling system might include modifications such as intentionally routing the trucks to all areas of the dump in order to achieve some surface compaction, the utilization of conventional compactors and rollers, control of placement to achieve drainage and stability, etc. When this is done, however, construction control techniques often predominate over the density or related technical control procedures, resulting in an improved but not necessarily adequate structure.

The placement of fine size coal refuse is almost exclusively by hydraulic methods, that is, materials pumped from the preparation plant to a settling pond. When the settling pond is the final disposal site for the fine refuse, control of the placement consists of varying the location of the discharge of the pipeline since the coarser particles will settle closer to the discharge point, and the fine particles further away where the ponding of the water is occurring. The effect of the point of discharge, with the resulting segregation, can be of significant importance to the stability of an impoundment. In recent years, incised ponds adjacent to the preparation plant have been utilized for plant water clarification, particularly where process equipment such as thickeners can perform the primary solids removal work. These ponds are usually of a smaller volume than the conventional refuse embankment impoundments, and must be cleaned periodically of the settled solids. This method requires an excavator, such as a dragline or a front end loader to load the settled materials for haulage to the final disposal site. The treatment or utilization of the fine materials at the dump or embankment then depends upon the method of construction in use at the site.

10.2 MATERIALS HANDLING

With increased emphasis on clean fuels coupled with technologically sophisticated extraction practices, the percent of material discarded as refuse per ton of mined materials has increased. Presently more than 20 percent of the total raw coal production is considered refuse. This figure is increasing and may reach as high as 40 percent by 1980 according to industry estimates.

10.2.1 Refuse Handling by Aerial Tramway

Aerial tramway handling is widely used in the hilly Appalachian coal fields. Preparation plants in this region are commonly situated in the valleys, and the disposal areas are usually over the top of the adjacent hills. Aerial tramways are ideal in this application since many times the slopes are too great for truck disposal methods.

Tramcar sizes vary in capacity from 10 to 90 cu. yds. and are able to travel at rates of up to 1750 fpm. Tramways seldom are operated at less than 1000 fpm. This type of system hauls and dumps the refuse at any point below the track cables. The system is set up so as to be "fail safe" enabling the tramway to stop in case of any malfunction.

10.2.2 Refuse Handling by Belt Conveyor

The use of a belt conveyor system for refuse handling involves the removal of refuse via the belt to a location adjacent to the disposal area where it is distributed by truck, scraper loader or stacker units. Bins are used at the discharge end if the truck or scraper loader distribution is being used, but these are not necessary when stacker distribution is being used.

Belt conveyors are able to attain high tonnage rates over grades which would make wheeled vehicles inefficient. However, use of belt conveyors should be evaluated carefully since the cost per ton mile tends to remain constant no matter how far the belt is extended, whereas

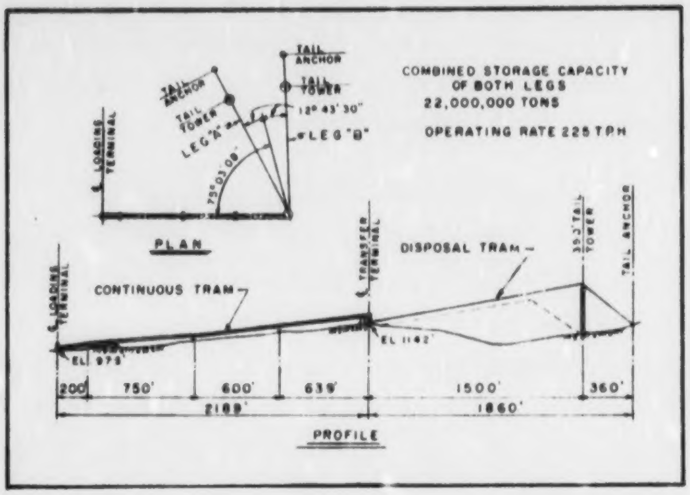

Figure 10-1
Continuous Aerial Tramway

Source: Interstate Equipment Corporation

the cost per ton mile for wheeled vehicles tends to decrease as the haulage distance increases.

Continuous combination conveyor systems are used at many installations, consisting primarily of a conveyor and elevator arrangement. These units operate in one direction and are able to negotiate slopes in excess of 30 degrees. The carriers range in capacity from 6 to 10 cu. yds. and the tramways are generally operated at speeds between 400 and 600 fpm.

Belt size is dependent on factors such as desired refuse removal rate, refuse characteristics (e.g., density and flowability) and haul profile. Also, various idler configurations are available. Conventional three-roll idlers are provided in widths from 18 through 72 inches. They are commonly spaced at 4 to 5 feet intervals on channel or truss frames. Figure 10-3 shows a cross section view of a three-roll idler belt arrangement.

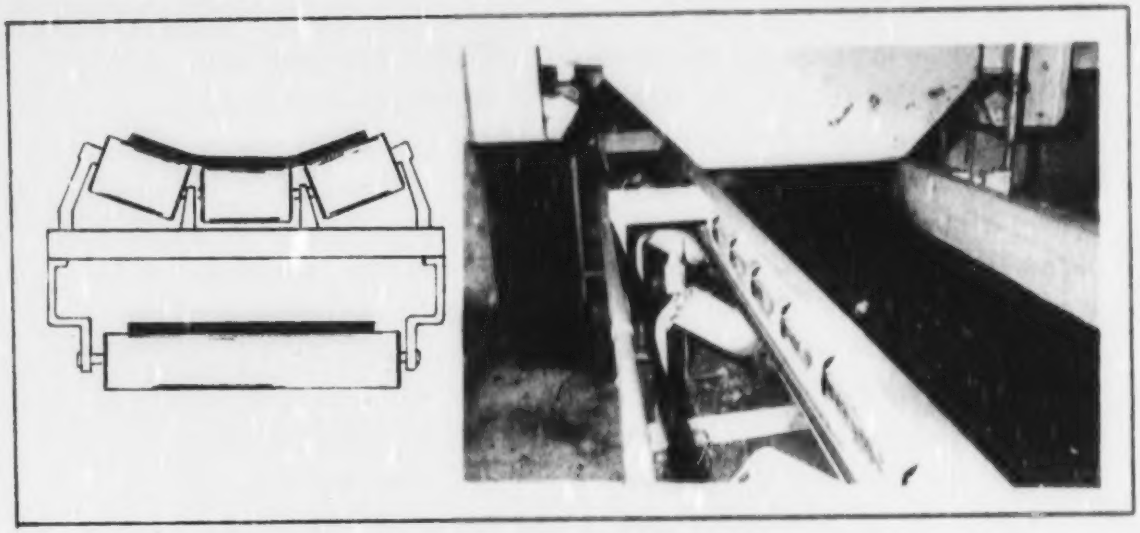

Figure 10-2
Three-Roll Idler Conveyor Belt System

A common feature of refuse disposal conveyor belts is the turned-over or reversed-return run where the belt is mechanically twisted to prevent the wet, refuse-carrying side from contacting the return idlers. This provides advantages such as decreased wear on the return idler shell, prevents build-up of wet sticky material on the return idlers and consequent adverse effect on belt alignment, and prevents deposition of carry-back material along the beltway.

10.2.3 Vehicular Haulage Units

Trucks and scraper loaders have long been used to disperse material at the immediate disposal area. Trucks are also being used increasingly as primary haul units from the plant to the disposal area, mainly due to the increased sizes of trucks now available. Three types of vehicles are suitable for refuse disposal:

- rear dump trucks,
- side dump trucks and
- scraper loaders.

Each vehicle type has the advantage of being able to spread the refuse thinly over the disposal area, a mandatory requirement for many of today's disposal areas. Compaction of the disposal area is facilitated by driving these vehicles over the area while discharging the loads. Using haulage units such as trucks for refuse disposal also provides greater flexibility; for example, dependency on a single unit, as in conveyor disposal, is greatly reduced when two or more trucks are used for primary refuse haulage. The disposal pattern can also be more readily adjusted to conform to natural contours, to develop stability or to gradually raise the level of the area above the existing landscape. Moreover, the capacity of the system can be increased simply with the addition of another unit.

To achieve these advantages, a common contemporary practice is using a combination of truck and belt conveyor transport for refuse handling. The belt is extended as far as is economically feasible, many times right to the disposal site. The belt discharges into a surge bin which is then used for loading the trucks or scrapers. Figure 10-4 depicts such a setup.

Another method of refuse handling is through slurry pipelines. This method has received more emphasis in recent years as the laws and regulations dealing with stream pollution have become more stringent. In general, greater use of hydraulic disposal is made for fine size refuse than for coarse refuse, primarily because of the high pressure head necessary to transport the coarse refuse through long lengths of pipe at steep grades.

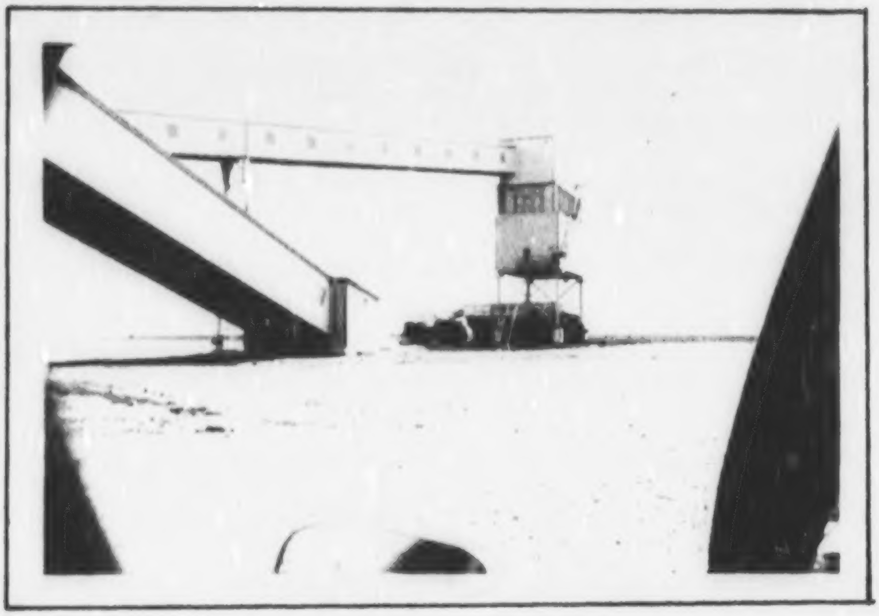

Figure 10-3

Combination Conveyor
and Truck Refuse Handling System

REFERENCES AND/OR ADDITIONAL READING

Bisselle, C.A.; Haus, S.A.; Lubore, S.H.; Scholl, M.M.; & Wilcox, S.L., "Strategic Environmental Assessment System: Initial Analysis of Environmental Residuals", The Mitre Corporation, February 1973

Black Sivalls & Bryson, Inc., "Study of Sulfur Recovery from Coal Refuse", U.S. Government Printing Office, September 1971

Charmbury, H.B., "Mineral Preparation Notebook", Pennsylvania State University

Chemical Construction Corporation, "The High Sulfur Combustor - A Study of Systems for Coal Refuse Processing", New York, New York, February 1971

Coal Age, "Coal Preparation and Unit-rain Loading", July 1972

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Coal Age, "Consol Preparation Confirms Coal Quality", October 1972

Coal Age, "Peabody Pioneers in Coal Handling & Preparation", Model Mining Issue, October 1971

Coal Age, "U.S. Steel Coal Preparation", Model Mining Issue, October 1973

Consolidation Coal Company, "Conveying a Slurry through a Pipeline", British Patent #861-537, February 1961

Cook. L., "Practical Application of Hydraulic Mining at Rahui Buller Coalfield", Paper 31, Mining Conference, School of Mines & Metallurgy, University of Otago, May 1953

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Dahlstron, D.A.; Silverblatt, C.E., "Dewatering of Pipeline Coal", U.S.A., Australian Coal Conference

D'Appolonia, E., "Engineering Criteria for Coal Waste Disposal", Mining Congress Journal, October 1973

Daub, Charles H., "The Oneida Plant", Mining Congress Journal, July 1974

Dean, K.C.; Havens, Richard; Glantz, M.W., "Methods and Costs for Stabilizing Fine-Sized Mineral Wastes", U.S. Bureau of Mines RI 7896 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Dokunin, A.V.; Onika, D.G., "Hydraulic Underground Mining", Translated for Branch of Bituminous Coal Research, Division of Bituminous Coal, U.S. Bureau of Mines

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Refuse Bank & Mine Fires", EPA-670/2-74-009, February 1974

Fairhurst, Charles, "European Practice in Underground Stowing of Waste from Active Coal Mines", First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 1974

Falkie, Thomas W., "Overview of Underground Refuse Disposal", Coal and the Environment Technical Conference, October 1975

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

Gospodarka, Gornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Gvozdek, G.; Macura, L., "Hydraulic Mining in Some Deep Pits in Czechoslovakia", Translated by National Coal Board (A 1683), Uhli #12, December 1958

Humboldt-Wedag, "Manufacturers Brochures", Cologne, Germany

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Provence Coalfield", France, Australian Coal Conference

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jeffrey Mining Machine Co., "Jeffrey Mining Machine Company: Manufacturers Information", Columbus, Ohio

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Knuth, William M., Jr.; Charbury, H. Beecher, "Remote Sensing Techniques for Analyses of Burning in Coal Refuse Banks", Coal and the Environment Technical Conference, October 1974

Korol, Dionizy, "Influence of Hydraulic Getting on Mechanical Coal Preparation", Przeglad Gorniczy, Year 12 #12, December 1956 (National Coal Board Translation Section)

Kosowski, Z.V., "Control of Mine Drainage from Coal Mine Mineral Wastes, Phase II - Pollution Abatement & Monitoring", EPA 42-73-230 May 1973

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Leven, P., "Pumping: A Good Way to Dispose of Coal Plant Refuse", Coal Mining and Processing, June 1966

Lotz, Charles W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Magnuson, Malcolm O.; Baker, Eugene C., "State-of-the-Art in Extinguishing Refuse Pile Fires", Coal and the Environment Technical Conference, October 1974

Martin, John F., "Quality of Effluents from Coal Refuse Piles", Coal and the Environment Technical Conference, October 1974

Moulton, Lyle K.; Anderson, David A.; Hussain, S.M.; Seals, Roger K., "Coal Mine Refuse: An Engineering Manual", Coal and the Environment Technical Conference, October 1974

National Coal Association, "First Symposium on Mine & Preparation Plant Refuse Disposal", Coal and the Environment Technical Conference, October 1974

Patterson, Richard M., "Closed System Hydraulic Backfilling of Underground Voids", First Symposium on Mine and Preparation Plant Refuse Disposal. Coal and the Environment Technical Conference, October 1974

Poundstone, William, "Problems in Underground Disposal in Active Mines", First Symposium on Mine and Preparation Plant Refuse Disposal, Coal and the Environment Technical Conference, Louisville, Kentucky, October 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Roberts & Schaefer Company, "Manufacturers Information Booklets", Chicago, Illinois

Scott, Robert B., "Sealing of Coal Refuse Piles", Program Element 1B2040, NERC-USEPA, Cincinnati, Ohio, July, 1973

Shields, Donald H., "Innovations in Tailings Disposal", Coal and the Environment Technical Conference, October 1974

Wahler, William A., "Coal Refuse Regulations, Standards, Criteria and Guidelines", Coal and the Environment Technical Conference, October 1974

Wemco Division, "Manufacturer's Catalog", Envirotech Corporation, Sacramento, California, 1974

Yusa, M.; Suzuki, H.; Tanaka, S.; Igarashi, C., "Sludge Treatment Using A New Dehydrator", Japan, Australian Coal Conference

11. THE COMPLETE PREPARATION PLANT

11.1 OVERVIEW

For the purpose of clarity and to ease the understanding of the very complicated and interdependent process of the physical cleaning of coal, the discussion heretofore has addressed the individual process modules within the preparation plant. However, to gain a complete understanding of the physical coal cleaning process and its related costs, it is necessary to look at the preparation plant as a unitized entity.

As the pressures mount to preserve an acceptable environment and because the oxides of sulfur (principally sulfur dioxide (SO_2) that comes from the burning of sulfur-bearing coal and oil in stationary sources) ranks second in total quantity of pollutants discharged into the atmosphere, coupled with the projected significant increase in the quantity of coal to be consumed annually, it is readily apparent that a substantial reduction in the amount of SO_2 emitted to the atmosphere must be achieved. Studies conducted by the U.S. Environmental Protection Agency and the U.S. Bureau of Mines have indicated that relatively few American coals from the Eastern and Midwest coal producing areas may be cleaned to relatively low sulfur levels, i.e., to about one percent of total sulfur content, by the utilization of the best available physical coal preparation technology (see Chapter 4). Table 11-1 shows the percent of samples

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from the four major coal producing areas that will meet the EPA standard of 1.2 lbs SO_2/MBtu.

Table 11-1

Percent of Coal Samples Meeting EPA Standards of 1.2 lbs/SO_2 per MBtu*

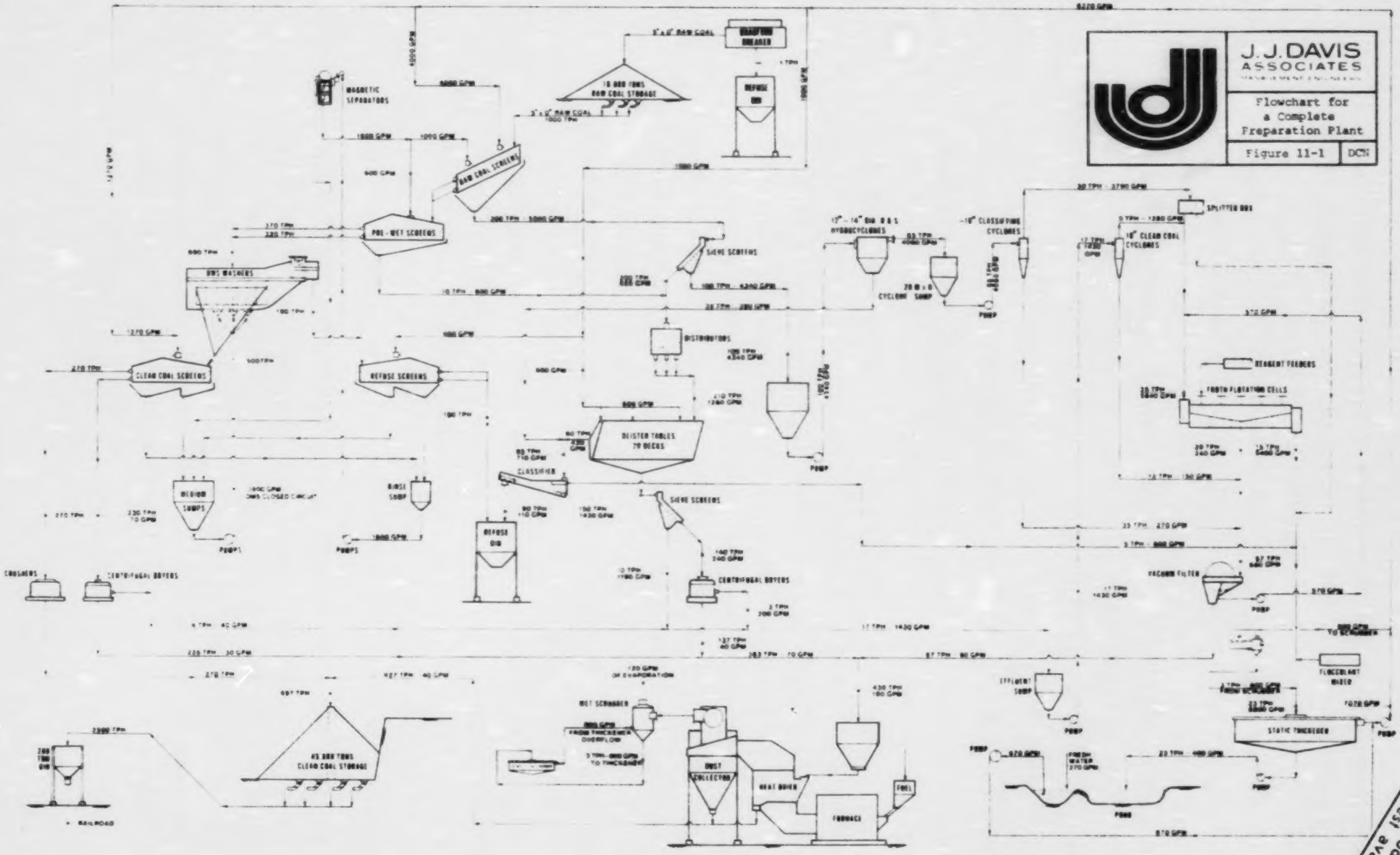
Region	% Meeting
Northern Appalachian	31
Southern Appalachian	63
Midwest	4
Western	98

* Based on crushing to pass 14-mesh and cleaning at a 50% Btu recovery.

As noted in Chapter 4, The Preparation Process, the range of coal cleaning practices in the United States is very broad; from no preparation and direct utilization of run-of-mine product to multi-stage cleaning with controlled particle size, maximum ash and pyritic sulfur removal, extensive dewatering including thermal drying, maximum calorific content and maximum product recovery. It is, however, anticipated that the majority of new preparation plants built will approach the maximum designed capability for ash and pyritic sulfur removal and will, therefore, fall into Level 4 as defined in Chapter 4. It is imperative, then, that a discussion of a complete "unitized" preparation plant address a maximized plant.

11.2 THE COMPLETE PLANT

Figure 11.1 is a flow chart for a typical, modern preparation plant as defined by Level 4 in Chapter 4. The



Flowchart for
a Complete
Preparation Plant

Figure 11-1

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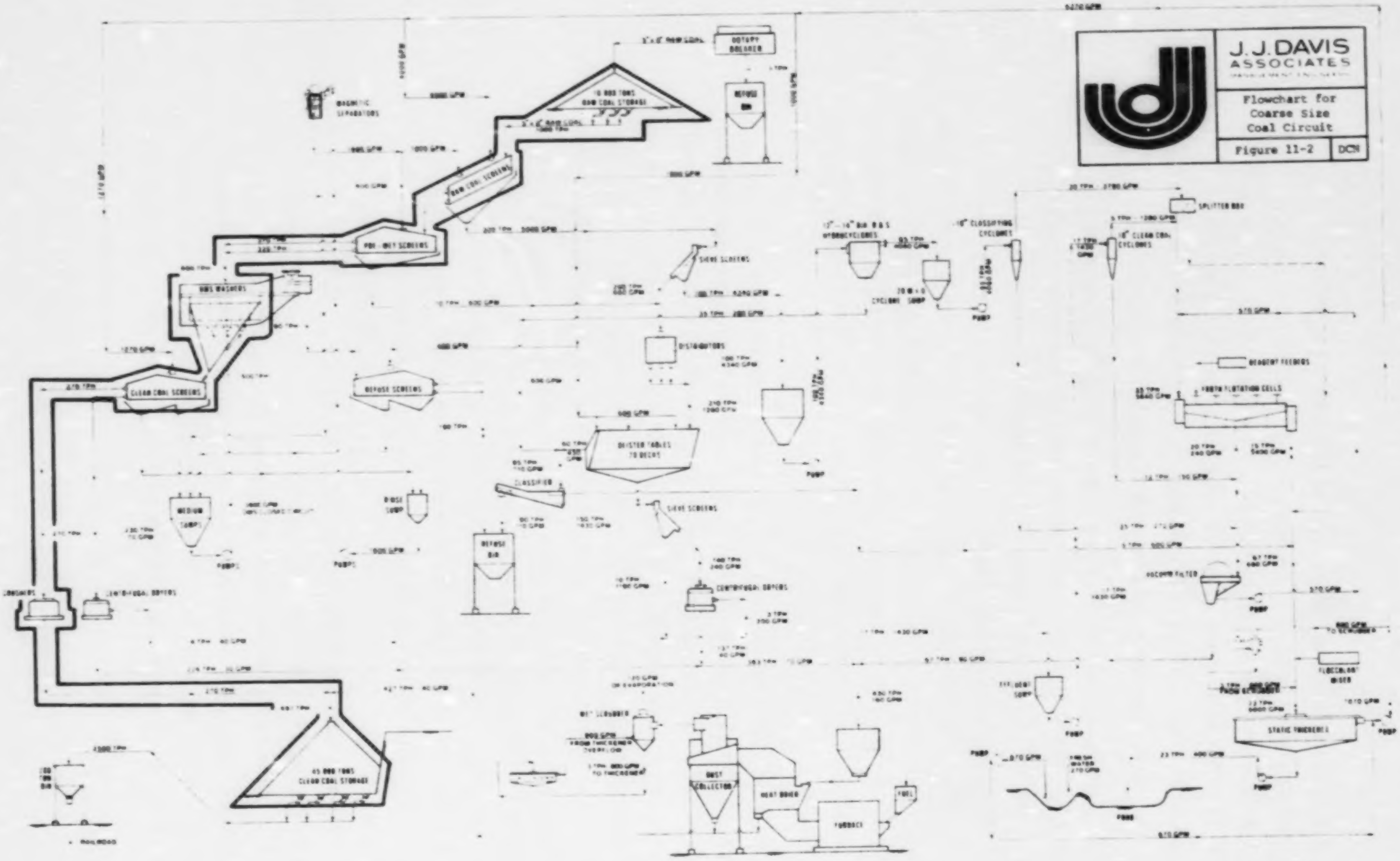
diagram contains all of the elements of the process modules defined in Chapter 4 and a majority of the equipment types discussed in Chapters 5 through 10. Figures 11-2, 11-4 and 11-5 dissect Figure 11-1 and reduce it to the components of the coarse, intermediate and fine size coal cleaning circuits, respectively. By the selective elimination of first, the fine size coal cleaning circuit and secondly, the intermediate size coal cleaning circuit, a more complete understanding may be obtained for preparation plants falling into Levels 3 and 2, respectively.

11.2.1 The Coarse Size Coal Circuit

Figure 11-2 highlights the coarse size coal circuit. The run-of-mine coal enters the preparation plant area at a truck or rail car dump or directly from the mine via a belt conveyor. The ROM coal is conveyed directly to a rotary breaker where its top size is reduced to 5 or 6 inches. All material which will not degrade in size to 5 inches or less is eliminated from the system without further processing and transferred directly to the refuse bin. The coal and associated impurities which have been reduced in size to 5 inches or less are conveyed to the raw coal storage facility (see Chapter 5, Raw Coal Storage and Handling, for details). The ROM coal is stationary while in storage. Upon entering the actual preparation plant, the coal will remain in constant motion until it completes its circuit and is once again stabilized in the clean coal storage facility or, if refuse, until it reaches its final destination in the refuse pile or slurry pond.

When the ROM coal enters the preparation plant from the raw coal storage facility, it first encounters a raw coal screen which begins the initial size separation process. All coal larger than ½" is transmitted directly to the pre-wet screen where it is hit with water sprays to deslime (removal of the small particles sticking to the



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Flowchart for
Coarse Size
Coal Circuit

Figure 11-2

DCN

large particles and removal of silt and clays) the coal and to thoroughly wet it to simplify the dense media washing process. (See Chapter 6, Product Sizing, for details.) The ROM coal smaller than ½", including the products carried by the water from the pre-wet screen enters the intermediate size coal cleaning circuit.

The raw coal passing over the pre-wet screen is transmitted directly to the Dense Media Separator where raw coal separation is achieved through a closely controlled specific gravity bath. All product (coal) with a specific gravity of approximately 1.4 (in this case) floats or remains in the top of the washer and all product heavier than the 1.4 specific gravity settles and is removed by the refuse removal system. (See Chapter 7, Product Separation, for details.)

The overflow from the dense media washer (float product) is conveyed directly to a clean coal screen where the coal is first drained of the excess dense media (usually magnetite) and then washed with clean spray water to remove any of the dense media still clinging to the coal. The clean coal is then dewatered by the vibrating action of the screen. The refuse product of underflow from the dense media washer is conveyed directly to a refuse screen where it is first allowed to drain. The refuse is then washed with spray water to remove any remaining dense media and finally dewatered by the vibrating action of the screen and conveyed directly to the refuse bin. (See Chapter 8, Product Dewatering and Drying, for details.) The underflow from the drain portion of both the clean coal screen and the refuse screen is piped directly to the dense media sump and returned to the dense media washer. The underflow from the spray wash area of these screens is piped to the rinse sump from which it enters the media recovery circuit discussed in Figure 7-16. Figure 11-3 illustrates the activities surrounding the clean coal and refuse screens.

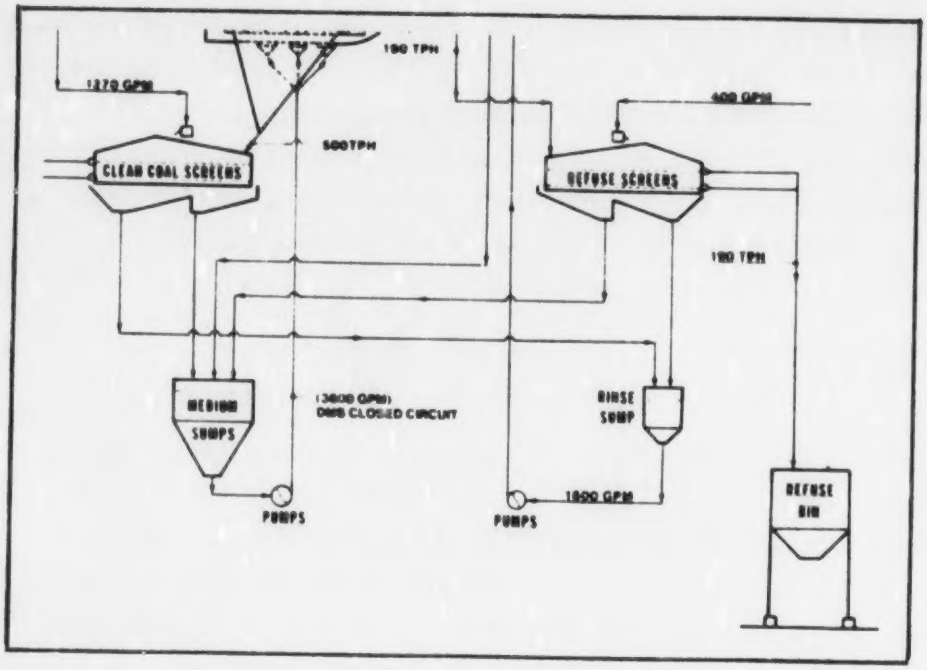


Figure 11-3
Highlights of the Drain and Rinse Process
in the Coarse Coal Circuit

The product (clean coal) from the top deck of the clean coal screen (coal larger than ½ inch in this case) is considered to have been sufficiently dewatered by the screen, i.e., its surface moisture has been reduced to 10% or less, and will, therefore, not require further dewatering. However, the coal larger than 1½" is usually reduced to a smaller size before storage. In this example, the coal oversize on 1½" screens is conveyed directly to a coal crusher where its top size is reduced to 1¼" or less. The product from the coal crusher is conveyed to the clean coal storage facility. (See Chapter 9, Clean Coal Storage and Handling.)

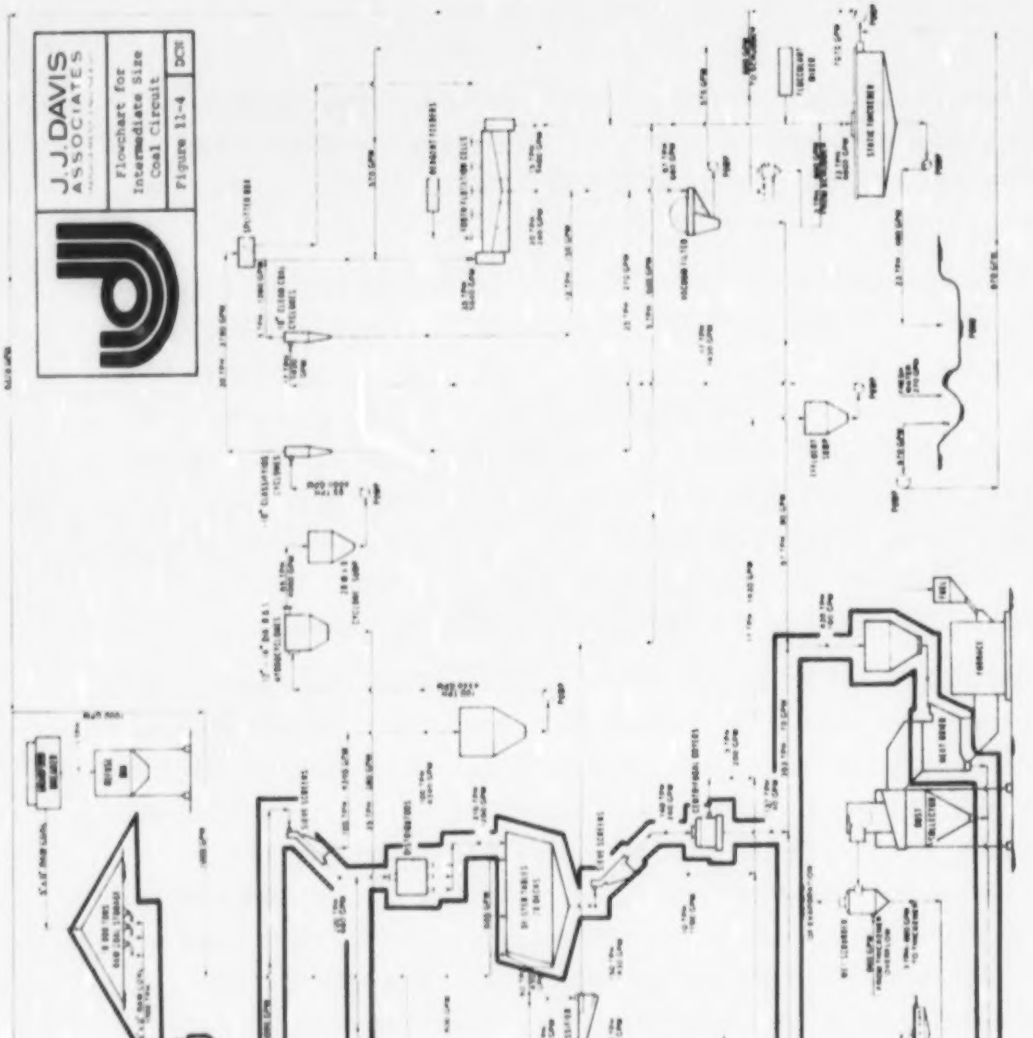
11.2.2 The Intermediate Size Coal Cleaning Circuit

The intermediate size coal cleaning circuit is defined as that portion of the preparation plant that cleans coal smaller than 3/4 or 1/2 inch, but generally larger than 48-mesh. As pointed out in Figure 11-4, which highlights the intermediate size coal cleaning circuit, the circuit in this example may be considered as having three individual points of origin:

- the underflow of the raw coal screen,
- the underflow of the pre-wet screen and
- the product of the second or bottom deck of the clean coal screen in the coarse coal circuit.

As discussed in earlier chapters and as shown in Figures 11-4 and 11-5, there is considerable overlap of equipment and functions within the preparation plant. For the purpose of clarity, every attempt is made to keep the discussion confined to the linear flow. It should be kept in mind that the flow is not always linear and that the flow may in fact backtrack upon itself and that the definitive and arbitrary ground rules for describing the coarse, intermediate and fine size coal circuits are highly flexible and subject to a multitude of variables and interpretations.

Referring to Figure 11-4, the underflow from the raw coal screen contains the majority of the ROM feed stock that is 3/4" or smaller in size. This underflow slurry is piped directly to a sieve screen where a separation is made at 28-mesh. The overflow from the sieve screen (particles larger than 28-mesh) is transported to the



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Flowchart for Intermediate Size Coal Circuit

Figure 11-4

DCH

distributors for the concentrating tables. The underflow from the sieve screen is piped to the hydrocyclone sump which in this example is considered to be in the fine size coal cleaning circuit.

A second point of entry to the intermediate size coal cleaning circuit is the underflow from the pre-wet screen in the coarse size coal circuit. This underflow contains the balance of particles smaller than 3/4" or ½" contained within the raw coal feed and that which has developed from size degradation during the initial screening process. The pre-wet screen underflow product reports directly to the distributor boxes for the concentrating tables. Refer to Chapter 6 for details of the product sizing process module.

The distributor boxes which collect the overflow from the sieve screen and the underflow from the pre-wet screens evenly distribute the combined products to 20 concentrating tables where the clean coal is collected as a product along the long side of the table, and the refuse product is collected along the short side of the table (see Chapter 7 for details). The refuse product, being a fairly coarse slurry (28-mesh or larger) is fed to a screw classifier where the solid product is collected and conveyed to the refuse bin. The remaining slurry of water and ultra-fine refuse product is piped to the static thickener for settling and eventual disposal. The clean coal product, on the other hand, is fed to a sieve bend to begin its dewatering and drying cycle. The sieve bend will make a separation at approximately 28-mesh with the overflow going to a centrifugal dryer and the underflow reporting to the fine size coal cleaning circuit.

The third entry point to the intermediate size coal cleaning circuit in this example is the product of the second deck of the clean coal screen in the coarse size coal circuit. The clean coal product from the bottom deck of the clean coal screen is conveyed directly to the centrifugal dryers. This product is usually one inch or smaller in size. As noted, the parameters of the intermediate size coal cleaning circuit generally refer to 3/4" or ½" and smaller particles. However, at this point in the process module the coal has been cleaned within its appropriate process module and is being combined during the dewatering and drying process group. As pointed out in Chapter 8, the percent of surface area increases as the product size decreases. As the percentage of surface area increases, the moisture retention per unit weight increases. The surface moisture of the top deck product of the clean coal screen has been reduced to 10% or less; however, the surface moisture of the bottom deck product may be as high as 30% or more necessitating an additional dewatering and drying step.

The slurry overflow product (moisture and ultra-fines) from the individual centrifugal dryers is piped directly to the effluent sump from which it enters the fine size coal cleaning circuit. The centrifugal underflow product as depicted in Figure 8-13 is conveyed to a thermal dryer for final drying (see Chapter 8 for details). Upon completion of the thermal drying process, the intermediate size clean coal product is combined with the coarse size coal product in the clean coal storage facility.

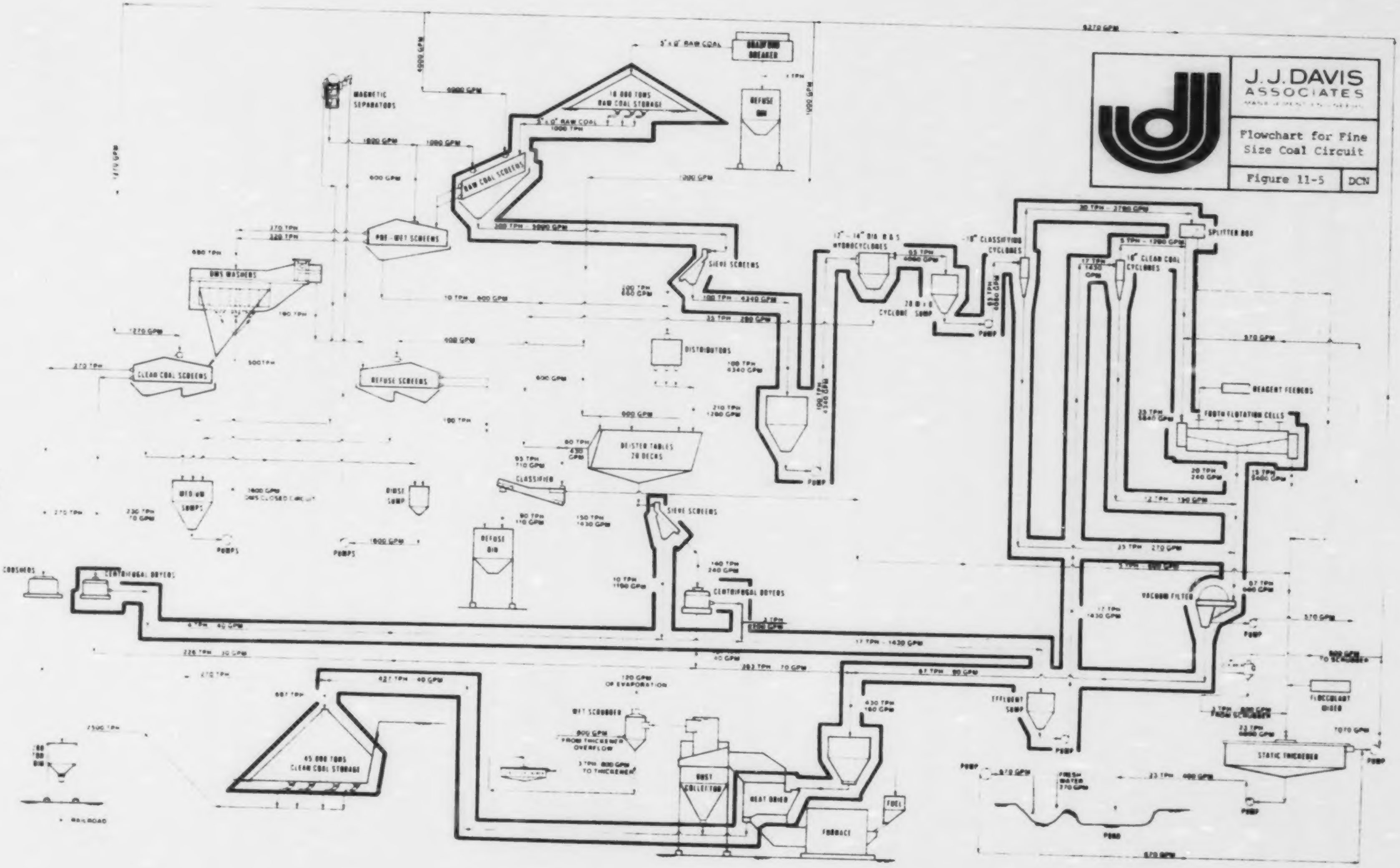
11.2.3 The Fine Size Coal Cleaning Circuit

Figure 11-5 highlights the fine size coal cleaning circuit in the exampled preparation plant. For the purpose of this discussion, the fine size coal cleaning circuit is defined as that portion of the preparation plant coal washing circuit that processes coal and refuse products 28-mesh or smaller. It must be noted that all of the equipment contained within this description with the exception of the froth flotation module may be classified as belonging to the intermediate size cleaning circuit in a different example, i.e., a metallurgical coal cleaning plant which produces a low sulfur clean coal product as well as a high sulfur middlings product.

As may be observed from Figure 11-5, the fine size coal cleaning circuit feed has three points of origin:

1. the underflow from the initial sieve screen in the intermediate size coal cleaning circuit,
2. the underflow from the sieve bend screening of the concentrating tables' clean coal product slurry and
3. the slurry and ultra-fine effluent from the centrifugal dryers.

In this example, the largest portion of feed stock for the fine size coal cleaning circuit comes from the underflow of the initial sieve screens in the intermediate size coal cleaning circuit. This slurry of coal and refuse flows by gravity to a hydrocyclone sump on the bottom floor of the preparation plant where it is pumped to hydrocyclones for hydraulic product separation as discussed in detail in Chapter 7. The underflow (refuse) from the large hydrocyclones is piped to a screw classifier where it mixes with the reject product from the concentrating tables and is subsequently removed to the refuse pile or slurry pond as previously described or, more typically, this underflow would be retreated on the tables or in a dense-medium cyclone. The overflow clean coal product (approximately 65% of the feed solids) is piped to the cyclone sump where it is collected and pumped to a bank of 10" classifying cyclones which make a product separation at approximately 48-mesh. Coal particles smaller than 48-mesh are contained in the overflow. The underflow product is routed directly



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Flowchart for Fine Size Coal Circuit

Figure 11-5

DCN

to the vacuum filter for recovery and initial dewatering (see Chapter 8). The overflow product is piped to a splitter box which feeds the froth flotation circuit. (Note: Flotation circuits typically treat 28-m x 0, 48-m x 0 or 100-m x 0.)

The second point of origin for the fine size coal circuit is the underflow from the sieve bend which is the initial dewatering device for the clean coal product of the concentrating table module. The third point of origin for the fine size coal cleaning circuit is the effluent slurry from the centrifugal dryers. The ultra-fine coal slurry products of the sieve bend and the centrifugal dryers are piped to the effluent sump from which they are pumped to the bank of clean coal classifying cyclones. The overflow from these cyclones reports to the froth flotation module and the underflow, 48-mesh or larger, reports to the vacuum filter module for recovery.

The minus 48-mesh size cyclone overflow products collected in the splitter box are equally distributed by the splitter box to the various froth flotation cell groups. In a single stage froth flotation circuit, the float product is skimmed off the top of the cells as the clean coal product and is piped to the vacuum filter for initial recovery and dewatering. The sink product or refuse effluent is piped to a static thickener for recovery and disposal. In the U. S. Bureau of Mines two-stage froth flotation process, the float product is piped to a second set of froth cells where the sink product (clean coal) is routed to the vacuum filter module and the float product (pyrite) joins the sink product (refuse) of the first stage flotation cells and is piped to the static thickener (review Chapter 8 for details).

The product recovered by the vacuum filter (described in Chapter 8) is conveyed to the thermal dryer where it joins the clean coal product of the intermediate size coal circuit for final drying. Upon completion of the thermal drying operation, this combined clean coal product joins the clean coal from the coarse and intermediate size coal cleaning circuits in the clean coal storage facility.

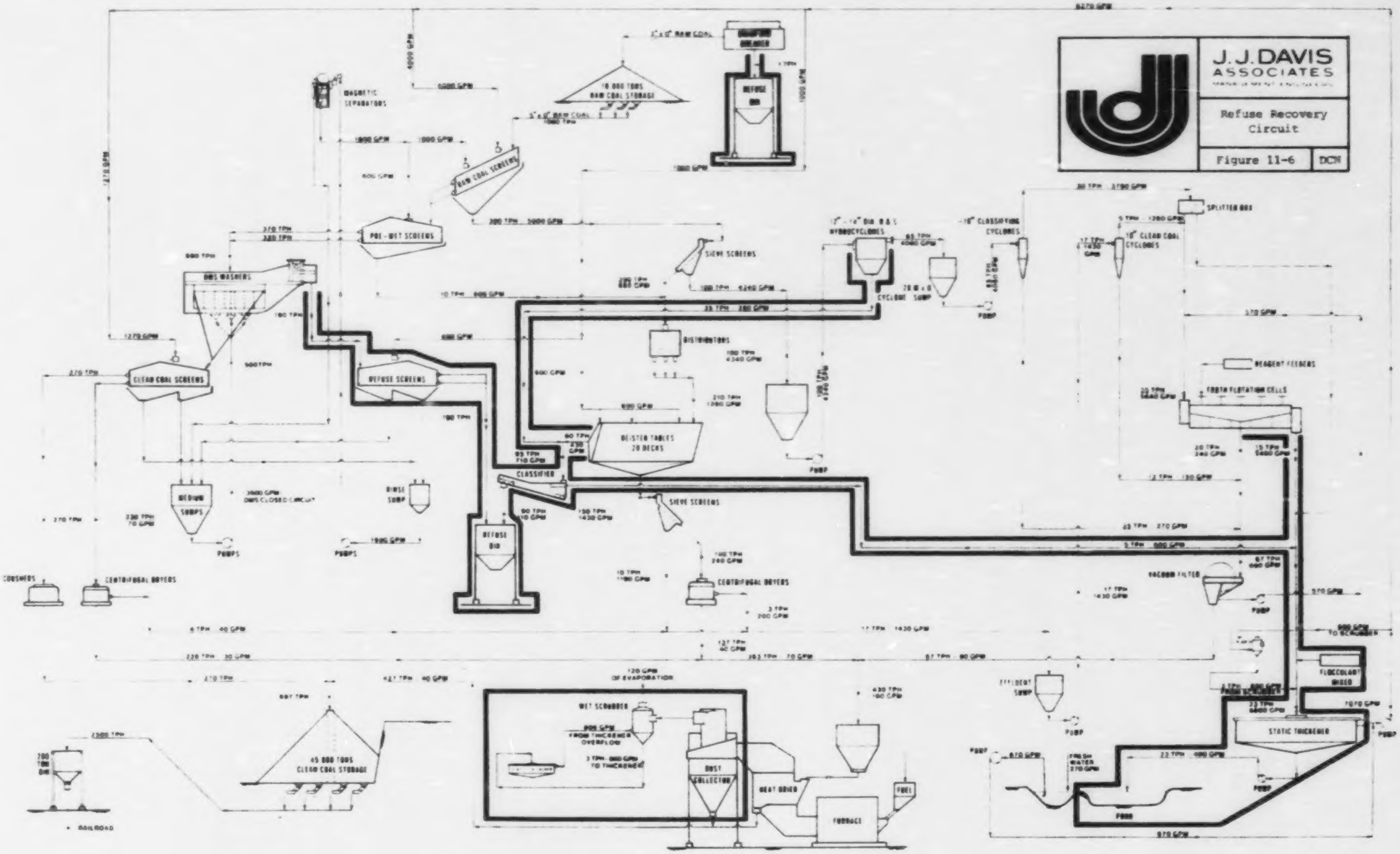
11.2.4 The Refuse Recovery Circuit

Figure 11-6 highlights the refuse recovery circuit of this particular flowsheet. The recovery circuit is broken down into four major areas:

1. solids recovery--dry,
2. refuse slurry concentration and solids disposal,
3. refuse slurry concentration and slurry disposal and
4. dust collection and disposal.

The dry solids recovery and disposal is simple and straightforward. The refuse solids are generated in the coarse coal circuit (as noted in Section 11.2.1) as reject material from the rotary breaker and as dewatered solids from the coarse refuse screen. These solids are conveyed directly to the refuse bin where they await transport to the solids disposal area (see Chapter 10, Refuse Handling, for details).

The refuse slurry and dry solids disposal circuit is also straightforward. The water and refuse slurry from both the hydrocyclone module and the concentrating table module in the intermediate and fine size coal cleaning circuit is piped directly to a spiral classifier. The classifier concentrates the larger solids (plus 28-mesh) and discharges them to a conveyor system for transport to the refuse



Refuse Recovery
Circuit

Figure 11-6

bin. The moisture carried out of the classifier is collected via natural drainage during the conveying process and piped to the static thickener.

The refuse ultra-fines, including the silt and clay particles generated throughout the coal washing system, are collected as a slurry underflow from the spiral classifier or as a slurry underflow from the froth flotation module. This slurry is piped directly to the static thickener where it is concentrated with the aid of various flocculants and piped in a highly concentrated slurry form to the refuse pond. The clarified water overflow from the static thickener is returned to the plant water system. In a more sophisticated preparation plant, the thickened concentrate underflow from the static thickener would be routed to a refuse recovery vacuum filter and the filtrate would be conveyed to the refuse bin for later transport to the waste dump.

The dust collection system in this example consists only of a dust collector and wet scrubber attached to the thermal drying module. The slurry generated from the wet scrubber is piped to the static thickener.

11.2.5 Process Quantities

To comprehend the physical coal cleaning process and to obtain an overall perspective of the material flow within the preparation plant, it is imperative that process quantities expressed in terms of percent of total product processed be understood. Table 11-2 summarizes the product quantities found in Figure 11-7 by coarse, intermediate and fine size coal circuits. These figures are based on a ROM coal feed of 1000 tons per hour (tph) to a plant utilizing 7070 gallons per minute (gpm) of process water with a yield of 697 tph clean coal and 303 tph reject material.

Table 11-2

Process Quantities For a Typical 1000 tph Coal Cleaning Plant

Note: Reference Figures 11-1, 11-2, 11-4, 11-5 and 11-6

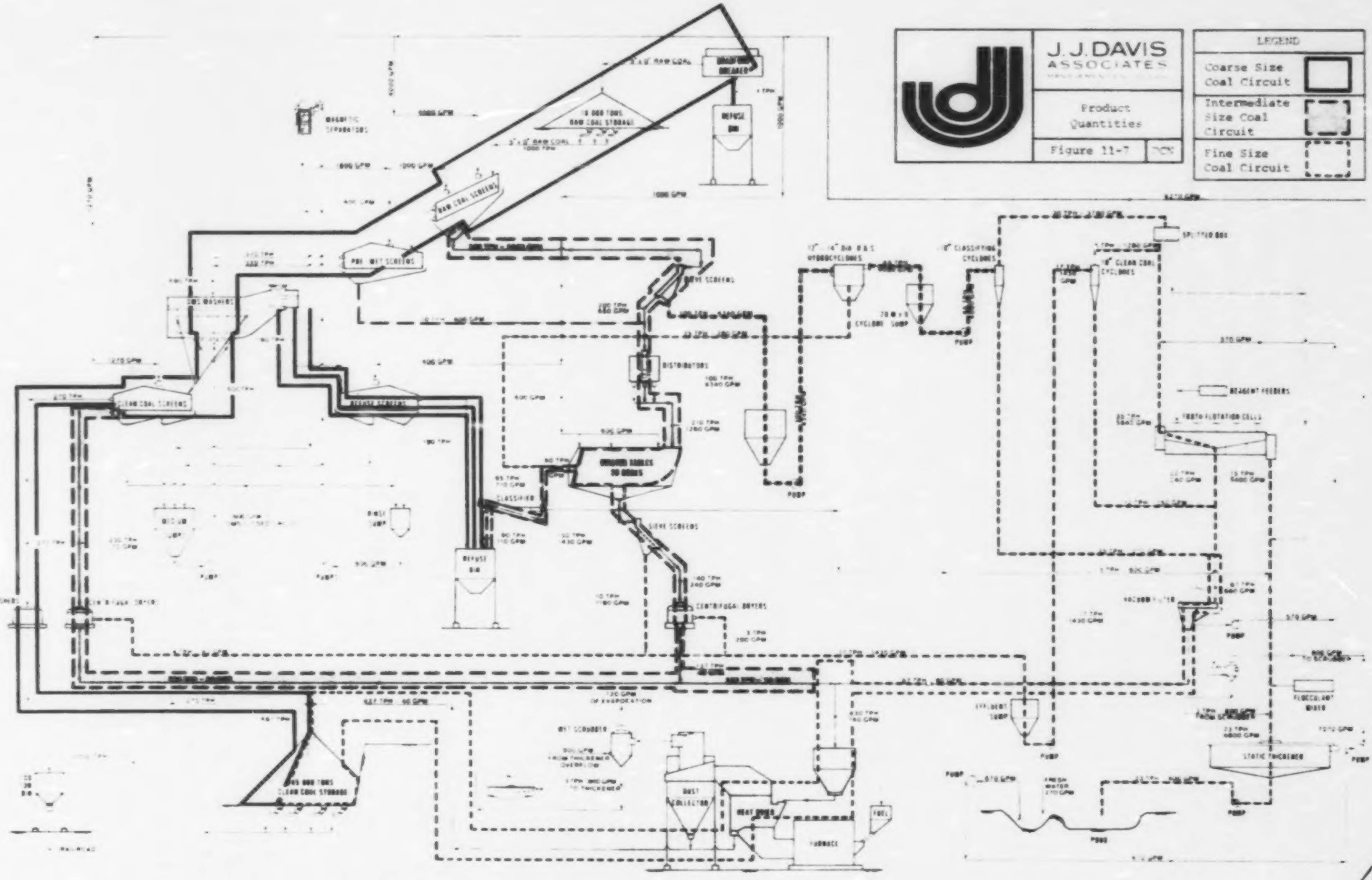
Coarse Size Coal		Intermediate Size Coal		Fine Size Coal		Tot. tph	Refuse	
tph	% of Total	tph	% of Total	tph	% of Total		tph	% of total
Washing Circuit		Washing Circuit		Washing Circuit			Coarse Size Refuse Recovery	
690 tph	69%	210 tph	21%	100 tph	10%	1000	190 tph	62.7%
Dewatering Circuit		Dewatering and Drying		Dewatering and Drying			Intermediate Size Refuse Recovery	
		226 (From Coarse Coal Circuit)		47 (Classifying Cyclones)			90 tph	29.7%
		137 (From Concentrating Tables)		20 (Froth Flotation)			Fine Size Refuse Recovery	
				-3 (Dust Loss to Thermal Dryer)			20 tph	6.6%
270 tph	38.7%	363 tph	52.1%	64 tph	9.2%	697	Thermal Dryer Dust	
							3 tph	1.0%
						303	Total Refuse	
						1000 tph		
870 GPM	12.3%	1860 GPM	26.3%	4340 GPM	61.4%			
Process Water		Process Water		Process Water				

A review of Table 11-2 shows that the coarse size coal circuit processed 69% of the total plant feed with a clean coal yield of 71% or 496 tph. The intermediate size coal circuit washes 21% of the total plant feed with a yield of 65% or 137 tph; however, the intermediate size coal circuit must dewater and dry 52.1% of the total clean coal yield. The fine size coal circuit washes 10% of the total plant feed with a yield of 64% or 64 tph and dewaters and dries 9.2% of the total clean coal yield. Figures 11-7a, b and c graphically display the relative process quantities (the thickness of the varying lines represents the percentage of the total product being processed through the coarse, intermediate and fine size coal circuits).

11.3 THE ECONOMICS AND MANAGEMENT OF COAL PREPARATION

Other than the general guidelines discussed in Table 4-1, it is beyond this discussion to outline or define specific costs for the physical cleaning of coal (particularly in view of today's changing economy). However, a general discussion of the economic aspects, design and operational characteristics of coal cleaning plants may be beneficial.

The overall economics and management of a coal preparation facility are governed by a number of interdependent parameters which individually and collectively affect the final performance. A preparation plant's benefit to the operator, and ultimately to the customer, is measured through its return on investment. The sensitivity analysis desplayed in Figure 11-8 and 11-9 shows how the various parameters affect the return on investment through unfavorable change from planned or expected values. As illustrated in Figure 11-8, for metallurgical coals, the selling price negotiated is the primary and most sensitive variable, followed by the yield,



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Product Quantities

Figure 11-7 DCN

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mining costs and transportation. It is clearly indicated that the ROI is the least sensitive to the coal preparation plant capital and operating costs (overhead).

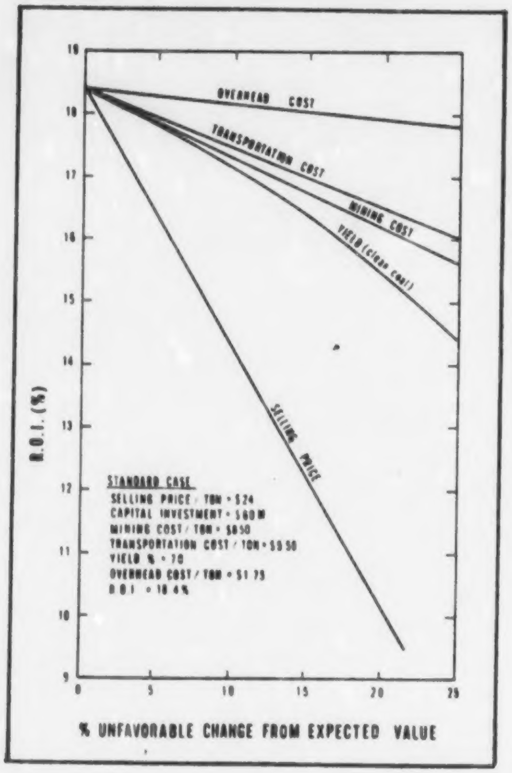

Figure 11-8

Sensitivity Analysis for Metallurgical Coal

Source: Birtley Engineering, Salt Lake City, Utah

For energy (steam) coal, the selling price is determined by heat energy content (x cents per million Btu's) and is, therefore, not considered as an independent variable. As Figure 11-9 illustrates, the transportation of the clean coal product is the major factor affecting the level of income followed by yield and mining costs. Again, the operational costs and capital investment are relatively non-sensitive variables.

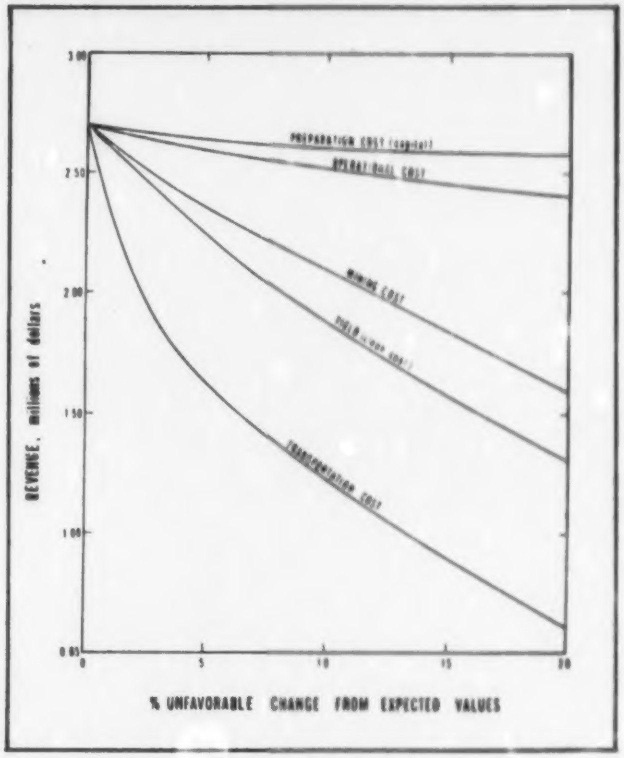

Figure 11-9

Sensitivity Analysis for Steam Coal

Source: Birtley Engineering, Salt Lake City, Utah

Most of the factors considered in Figures 11-8 and 11-9 are fixed and beyond the control of the preparation plant and, as shown, any change from the expected or planned values dramatically impacts revenue and R.O.I. However, one variable--clean coal yield--is to a great extent controllable within the preparation plant. Once the theoretical yield for a particular coal has been determined, the optimum return is achieved by approaching that recovery level as nearly as possible. Using the standard case data presented in Figure 11-8 (selling price of $35/ton for metallurgical coal), a one percent increase in yield from 75% to 76% for a facility producing 2 million tons of coal annually would result in a net revenue increase of $700,000.

The optimization of the clean coal yield is dependent upon successful design and operation of the preparation plant. The most important step towards the ultimate success of the plant is the selection of the flowsheet. The actual design of the physical structure, the placement of the equipment, the availability of an adequate water supply, etc., are ancillary and are usually dependent upon the process flow selected. In the selection of the flowsheet, several questions must be asked. The answers to these questions must be clearly defined and well documented. The most important questions are:

- What are the properties of the raw coal?
- What are the washability characteristics of the raw coal?
- Will further reduction of ash, sulfur or moisture improve either the salability or the realization?

11.3.1 Defining Properties of Raw Coal

Coals vary considerably in quality; therefore, it is necessary to determine the properties of a given coal to effectively evaluate its worth for a specific use.

Electric utilities pay for coal on its effective heat value with appropriate credits or penalties if the properties of given clean coal vary from the established ash, sulfur or moisture levels. Steel companies judge coal as to its coking strength, expansion or swelling properties, ash-sulfur-phosphorous-carbon content and how well it blends with other coals to make a good coke.

In the establishment of the properties of a given coal the coal is ordinarily analyzed first as to its "proximate" or "ultimate" analysis:

- Proximate Analysis--is used to determine the moisture, volatile matter, ash content and fixed carbon content of a specific coal.

Proximate	Analysis, %
Moisture	_____
Fixed Carbon	_____
Volatile Matter	_____
Ash	_____
Total	100.0

The ash and moisture content are important because they affect the heating value of the coal. Additionally, the moisture content may influence the capacity of the pulverizer used in pulverized coal burning systems and the ash content is a major contributor to slag in the blast furnace and will remain in the coke in coking coals. The volatile matter content reflects coke yield, is an indicator of coke quality, is indicative of the ignition temperature of the coal and correlates with the amount of theoretical air need for combustion and the fineness of pulverization required for the most effective use of the coal as a fuel.

- Ultimate Analysis--is used to determine the carbon, hydrogen, oxygen, nitrogen, sulfur and ash content of a given coal. This analysis is used in combustion calculations to determine air requirements, and to obtain material balances in boiler tests. The amount of sulfur in the coal determines the air pollution potential and

Ultimate	Analysis, %
Carbon	____
Hydrogen	____
Oxygen	____
Nitrogen	____
Sulfur	____
Ash	____
Total	100.0

the corrosiveness of the combustion products. Additionally, the sulfur content of the coal used in steel making is apt to contaminate the metal product.

The coal is further analyzed depending upon its end use by any one or a series of tests as outlined by the following:

- Calorific Value--is used to determine the calorific or heating value of the coal expressed in Btu's per pound of coal. The calorific value is basic to obtaining heat balances in firing coal to produce heat or steam and it is usually specified in contracts for steam coal.

- Coal-Ash Fusibility--measures the temperature at which the coal-ash will soften and become fluid when heated under prescribed conditions. The type of burning equipment to be used governs the desirability of using coals with either low or high melting ash.

- Coal-Ash Composition--is reported as metal oxides and commonly included analysis for SiO_2, Al_2O_3, CaO, MgO, Na_2O, K_2O and P_2O_5. The ash composition is important in boiler design and operation and may be used as a guide in determining the fouling or corrosion characteristics of a coal or in predicting the ash-softening temperature.

- Free-Swelling Index--is used to determine a relative measure of the caking properties or free burning quality of a coal. The term caking refers to the fusion of the coal in a fuel bed into a large coherent mass that interferes with the uniform flow of air through the fuel bed and, therefore, determines the type of burning equipment to be used.

- Hardgrove Grindability Index--is a measure of the hardness of a given coal or the ease with which it may be pulverized.
- Audibert-Arnu Dilatometer and Gieseler Plastometer--tests are used to measure the plastic properties of a coal which are related to the viscosity of the fluid coal during the coking process. The best coking blend contains coals whose ranges of plasticity approximately coincide.

11.3.2 Washability Studies

To determine the preparation method and the equipment which is to be used to clean the coal (flowsheet development) washability studies must be conducted to determine the size and specific gravity distributions of the coal. All of the coal washing processes discussed in this presentation with the exception of froth flotation, effect a separation between the coal and its related impurities on the basis of the difference in the specific gravity of their components. Coals vary in the relative amounts of material of different densities present, and it is this factor that determines the washability or "upgrading" of the specific coal. Washability studies, then, are conducted to determine how much cleaned, salable coal can be produced at a given specific gravity level and with what degree of separation difficulty.

The washability studies of the specific coal are made by testing the coal sample at pre-selected, carefully controlled specific gravities. The specific gravity fractions are collected, dried, weighed and analyzed (generally) for ash and sulfur content. A table is compiled showing the weight percent of each specific gravity fraction, together with an analysis of that fraction. The data are mathematically combined on a weighted basis into "cumulative float" and "cumulative sink" and these combined data are used to develop the "washability curves" that are characteristic for that coal. This testing procedure is commonly termed float-and-sink analysis, or specific gravity fractionation.

The washability curves shown in Figure 11-10 are plotted from the data collected during the testing. Five curves are generally drawn from the data: Specific gravity (yield), cumulative-float ash, cumulative-sink ash, elementary ash and +0.10 specific gravity distribution. The most important of these curves are:

- specific-gravity (yield),
- cumulative float coal--ash and
- plus and minus 0.10 near gravity material distribution.

The specific-gravity (yield) curve is plotted directly from the cumulative-percent weight float data and specific-gravity fractions. This curve indicates the quantity of clean coal that can be theoretically obtained by washing at a certain specific gravity. The cumulative-float ash curve is plotted directly from the cumulative percent weight float and cumulative percent ash float and shows the theoretical amount of ash content in a particular quantity of floated coal. The ±0.10 specific-gravity distribution curve shows the percentage (by weight) of the coal that lies within plus 0.10 and minus 0.10 specific-gravity units at any given specific gravity. The plus and minus 0.10 near-gravity material distribution curve indicates the ease or difficulty of cleaning the particular coal being evaluated.

11.3.3 Determining Economical Washing Specific Gravities

As a general guide for determining the lowest practical specific gravity to wash a particular coal, especially

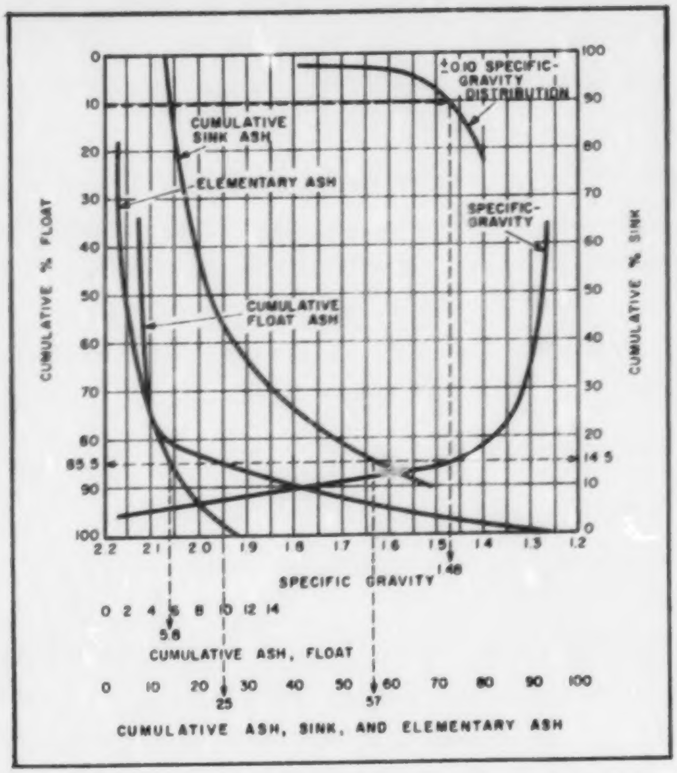

Figure 11-10

Typical Washability Curves

when jigs and tables are used, it is oftentimes arbitrarily designated that the point at which 10 percent of the total raw coal feed lies within ±0.10 specific gravity of the separating gravity is the lowest specific gravity at which it is practical to operate a coal cleaning plant. Most engineers will, therefore, utilize the ±0.10 specific gravity distribution curve as a starting point in predicting the product that may be expected from a particular coal. For example, referring to Figure 11-11 and assuming a separation at 10 percent near-gravity material in the float product, the following information may be obtained:

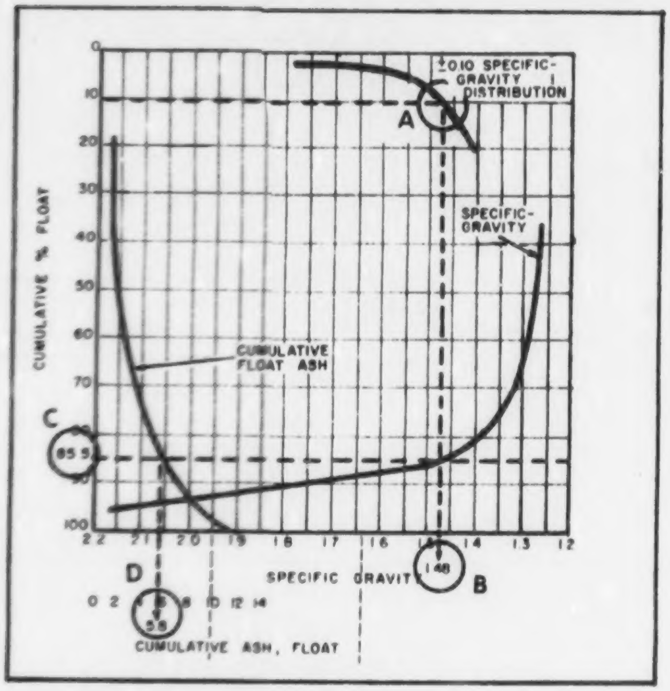

Figure 11-11

Determination of Economical Washing Specific Gravities

By projecting downward from the ±0.10 specific gravity curve (Point A), it is determined that the separating gravity for 10 percent near-gravity material in the float product will be 1.48 (Point B); the yield or float product will be 85.5% of the feed (Point C); the ash content of the float product will be 5.8% (Point D).

A careful review of Figure 11-11 will show that if a higher specific gravity is chosen at which to effect separation of the coal and its related impurities, the total ash content of the coal increases rapidly. If a lower specific gravity is selected as the washing gravity, then the percent of near-gravity material in the float product begins to reach totally unacceptable levels for Baum jigs and tables, as defined in Table 11-3.

Table 11-3

Impact of Near-Gravity Material on the Separation Process (for Tables and Baum Jigs Particularly; Not for Dense Medium Processes)

Quantity Within ± 0.10 Specific Gravity Range, percent	Ease of Separation
0-7	Simple
7-10	Moderately Difficult
10-15	Difficult
15-20	Very Difficult
20-25	Exceedingly Difficult
Above 25	Formidable

11.3.4 Selection of the Process Flowsheet

A very good picture of the make-up of a specific coal and the expected yield of an acceptable clean coal product can be obtained from the test data as outlined in Sections 11.3.1, 11.3.2 and 11.3.3. Once the quantity (tons per hour) of feed to the preparation plant and the size constituents of the feed stock have been determined, the test data are utilized to determine the preparation method or methods. The preparation method combined with the unique characteristics of the coal determine the equipment which must be selected to produce an acceptable clean coal product.

If, for example, the coal to be processed is easily cleanable (low percent near-gravity material) with a low sulfur content and fairly strong (does not degrade in size during processing) and if the size consist of the feed stock is primarily limited to the coarse coal sizes (70-80% over ¼ in.), then probably a very straightforward flowsheet can be selected. The coarse size of the feed will usually permit sufficient drying by natural drainage and mechanical dewatering eliminating the requirement for a thermal dryer. The low sulfur content will eliminate the need to reduce the size of the feed stock to liberate the pyrite. Without a requirement to dramatically reduce the size of the feed and with a low percentage of fines in the feed, an elaborate and expensive fine coal cleaning system will not be required.

On the other hand, if the feed has a high percent of fines (due to the nature of the coal or the mining method) of if the coal in question has a high sulfur content, then a very complicated and interrelated flowsheet must be selected to ensure an adequate yield with a clean coal product of acceptable ash and total sulfur content.

As noted in Section 11.3, the clean coal yield is the most sensitive factor in determining success or failure of a particular coal preparation plant (as related to return on investment). All of the variable discussed in Chapter 11 may directly affect the clean coal yield, and therefore the flowsheet required for a particular coal will determine whether or not that particular coal can economically be provided to a particular customer.

REFERENCES AND/OR ADDITIONAL READING

Bituminous Coal Research, Inc., "An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal", BCR Report L-339, September 1969, BCR Report L-362, February 1970, BCR Report L-404, April 1971, BCR Report L-464, April 1972

Black Sivalls & Bryson, Inc., "Study of Sulfur Recovery from Coal Refuse", U.S. Government Printing Office, September 1971

Blankenship, R.E., "Operational and Environmental Features of Virginia Pocahontas No. 3 Preparation Plant", Mining Congress Journal, April 1973

Blankmeister, W.; Bogenschneider, B.; Kubitaz, K.H.; Leininger, D.; Angerstein, L; Kohling, R., "Optimised Dewatering Below 10 MM", German, Australian Coal Conference

Boiko, V.A. Parinskiy, O.P., "Equipment for Dewatering of Coal", Chapter 5 of "Hydraulic Capability for Underground Mining of Coal", Katalog-Spravochnik, Moscow, 1965 (Translated by Terraspace)

Bowen, James B. & Guiliani, R.L., "The Integrated Occupational Health Program of the Erie Mining Comany", American Mining Congress Convention, Las Vegas, Nevada, October 1974

Burdon, R.G.; Booth, R.W.; Mishra, S.K., "Factors Influencing the Selection of Processes for the Beneficiation of Fine Coal", Australia, Australian Coal Conference

Chemical Construction Corporation, "The High Sulfur Combustor - A Study of Systems for Coal Refuse Processing", New York, New York, February 1971

Coal Age, "Multi-Stream Coal Cleaning System Promises Help With Sulfur Problem", January 1976

Coal Age, "U.S. Steel Coal Preparation", Model Mining Issue, October 1973

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Daub, Charles H., "The Oneida Plant", Mining Congress Journal, July 1974

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Deurbrouck, A.W., "Washing Fine-Size Coal in a Dense-Medium Cyclone", U.S. Bureau of Mines Report of Investigations #7892, 1974

Ellison, William; Hedsen, Stanley D.; Kominek, Edward G., "System Reliability and Environmental Impact of SO_2 Processes", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Gayle, J.G.; Smelley, A.G., "Selectivities of Laboratory Flotation and Float-Sink Separations of Coal", U.S. Bureau of Mines Report of Investigations #5691, 1960

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

Gregory, M.H., "Problems Associated with Closing Plant Water Circuits", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Grimm, Bobby M., "Preparation Plant Corrosion Cost", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Hoffman, L.; Truett, J.B.; Aresco, S.J., "An Interpretive Compilation of EPA Studies Related to Coal Quality and Cleanability", Mitre Corporation, May 1974 EPA 65012-74-030

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Provence Coalfield", France, Australian Coal Conference

Irminger, P.F.; Giberti, R.A., "Desulfurization Technology to Meet the Power Demand", NCA/BCR Coal Conference and Expo II, October 1975

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (translated by Terraspace)

Jenkinson, D.C., "Some New Coal Preparation Developments in the United Kingdom", National Coal Board Bulletin M4-B148

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Johakin, J., "Solving the SO_2 Problem--Where We Stand with Application and Costs", Coal Age, May 1975

Keystone, "Coal Preparation Methods in Use @ Mines", pp. 230-240

Kollodiy, K.K.; Borodulin, V.A.; Nazarov, P.G., "Processing of Coal Mined by the Hydraulic Method", Ugol #9, 1974 (Translated by Terraspace)

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Mettalurgical and Petroleum Engineers, Inc., 1968

Lowry, H.H. (Editor), "Chemistry of Coal Utilization", John Wiley & Sons, Inc., New York, New York, 1963

Martin, John F., "Quality of Effluents from Coal Refuse Piles", Coal and the Environment Technical Conference, October 1974

Martinka, Paul D.; Blair, A. Ross, "Western Coal Transportation - A Challenge", American Mining Congress Convention, October 1974

McNally-Pittsburg Manufacturing Corporation, "Coal Cleaning Plant Prototype Plant Design Drawings", Department of Health, Education and Welfare Contract 22-68-59

McNally-Pittsburg Manufacturing Corporation,"Coal Preparation Manual #572", Extensive Analysis on McNally Pittsburg Coal Cleaning Technology

McNally-Pittsburg Manufacturing Corporation "A Study of Design and Cost Analysis of a Prototype Coal Cleaning Plant", Department of Health,Education and Wealfare Contract PH 22-68-59

Miller, F.; Wilson, E.B., "Coal Dewatering - Some Technical and Economic Considerations", American Mining Congress Coal Convention, May 5-8, 1974

National Coal Association, "First Symposium on Mine & Preparation Plant Refuse Disposal", Coal and the Environment Technical Conference, October 1974

Norton, Gerry' Symonds, D.F.; Zimmerman, R.E., "Yield Optimization in Process Plan Economics", AIME Annual Meeting, New York, New York, February 1975

Nunenkamp, David C., "Survey of Coal Preparation Techniques for Hydraulically Mined Coal", Published for Terraspace Inc., July 1976

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

Protopapas, Panayotis, "A Report in Mineral Processing", Department of Applied Earth Sciences, Stanford University, 1973

Roberts & Schaefer Company, "Manufacturers Information Booklets", Chicago, Illinois

Roberts & Schaefer Company, "Design & Cost Analysis Study for Prototype Coal Cleaning Plant", August 1969

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant", January 1973

Terchick, A.A.; King, D.T.; Anderson, J.C., "Application and Utilization of the Enviro-Clear Thickener in a U.S. Steel Coal Preparation Plant", Transactions of the SME, Volume 258, June 1975

U.S. Bureau of Mines, "Methods of Analyzing and Testing Coal and Coke", Bulletin 638, Office of the Director of Coal Research, 1967

Wahler, William A., "Coal Refuse Regulations, Standards, Criteria and Guidelines", Coal and the Environment Technical Conference, October 1974

12. POTENTIAL POLLUTANTS

12.1 INTRODUCTION

The potential pollutants or materials which will have a deleterious impact on the land, air, water and animal life in and around coal preparation plants are becoming increasingly regulated by the individual states and to some extent by the Federal Government. It is anticipated that further Federal levels of control will be promulgated. It is, therefore, imperative that a basic understanding of the potential pollutants, i.e., source, be developed and that ultimately a complete understanding of methods or methodologies for control of such pollutants be achieved (see Chapter 13).

The deleterious effects to or the negative environmental interactions of coal preparation as it applies to the land include concerns of land usage, zoning regulations and coal waste piles and their stability, i.e., how these factors relate to site selection for the preparation plant (including transportation access), raw and clean coal storage facilities and refuse disposal practices.

The air pollution from coal preparation relates primarily to particulate emissions including fugitive dust from transportation, such as haul-roads, and from bulk handling of coal and coal waste products as well as particulate emissions from thermal drying processes and from burning refuse piles. There is also additional air

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pollution potential in the form of unacceptable, gaseous emissions from the thermal drying processes and from burning waste piles.

The potential water pollution from coal cleaning can affect both surface and ground water sources. The contaminants include water-soluble salts principally originating from the oxidation of pyrites, acids, iron-aluminum-sulfate ions, trace elements and suspended solids (coal and minerals) originating from the process water or added to it during coal cleaning as well as suspended solids from the runoff of waste piles and the immediate area of the plant site.

The direct environmental impacts to the animal life (including the plant work force) other than air and water revolve primarily around the noise generated by the transportation of coal and waste and by the individual process units within the coal cleaning plant.

12.2 IDENTIFICATION OF POTENTIAL POLLUTANTS

12.2.1 Solid Refuse

A study of the geologic foundation of coal is the first step in understanding the composition of the solid refuse from the coal cleaning operation. In addition to the impurities formed in the coal during its deposition, mineral impurities were carried by the ground water into the porous layers of fully developed coal seams. The mining, crushing and washing processes tend to concentrate many of these impurities in the refuse or gob.

Coal refuse consists primarily of coal, slate, carbonaceous and pyritic shales and clay associated with the coal seam. During the cleaning and preparation process, these materials are separated from the coal and are then disposed as spent or refuse materials. The refuse generated in the preparation plant consists of material ranging from colloidal size to 12-inch or large maximum particle size. Prior to the passage of environmental control legislation, the fine-grained portion was disposed in nearby streams or rivers, and the coarser materials on refuse piles. Subsequent to the implementation of the environmental legislation, the fine refuse is often pumped as a slurry to a settling pond where the suspended solids settle or are filtered from the water. The coarse refuse, which ranges upward in size from fine sands, is conveyed to the disposal area by trucks, scrapers, conveyors or aerial tram.

There are several unique characteristics of coal refuse material. First and most important from a physical properties standpoint, is the abnormally low specific gravity of the fine refuse which averages about 1.5 (see Table 12-1) as compared with an average soil value of 2.65. As a result of the low specific gravity value, the resulting in-place dry density of the fine material, regardless of its method of disposal, is also very low, with average values of 50 to 70 pounds per cubic foot. The low density of the fine wastes can create two deficiencies:

Table 12-1

Specific Gravity Results for Fine Coal Refuse

Number of Samples	Range of Specific Gravity
8	1.30 - 1.40
15	1.41 - 1.60
4	1.61 - 1.80
2	1.81 - 2.00
1	2.01 - 2.20
Average Specific Gravity = 1.53	

Source: W. A. Wahler and Associates

1) at low density, the material cannot adequately resist the upward flow of water from an impoundment and, therefore, if placed in the foundation area without proper ballasting from heavier materials, it can create serious problems of internal erosion (piping), and

2) the low density may result in the inability of the material to mobilize an adequate effective stress to resist shearing forces.

The coarse coal refuse, on the other hand, generally possesses a specific gravity more like that of a natural soil material. The coarse materials, however, contain flat, plate-like particles typical of slates and shales, which undergo rapid weathering to clay after the material has been deposited on the refuse pile. Also, if dumped in a loose fashion, the coarse coal refuse will have a high porosity (volume of voids) and tend to ignite by spontaneous combustion. The burning of the coarse refuse causes the material to fuse together, thereby resulting in a net volume reduction and the possible development of large voids in the materials during the burning process. Coal refuse and burned refuse, often called red dog, also tend to weather faster than most other alluvial or residual soils.

In an effort to build a model of a typical coarse coal refuse dump, W. H. Davidson of the USDA Forest Service conducted a physical and chemical analysis of 79 refuse piles typical of the major seams mined in each inspection district in Pennsylvania. In all, 304 samples were collected. Four samples each were taken from 72 piles, two from weathered refuse in the 0- to 6-inch layer and two from unweathered refuse at the 24-inch depth. Seven piles were too small to warrant taking four samples, so only one surface and one deep sample were taken. Each sample consisted of a composite of material from two holes about 10 feet apart, and each weighed about 20 pounds. Samples were placed in labeled paper bags and air dried.

Physical analysis of the samples consisted of separating the refuse into four size classes: less than 2 mm (soil size), 2 mm to 1/4 inch, 1/4 inch to 2 inches, and over 2 inches. Each sample was then analyzed, by standard laboratory methods, for the following chemical properties: pH, total acidity (meq H^+/100 gm), conductance (mmho/cm), sulfates (ppm SO_4) and phosphorus (ppm P).

After physical and chemical analysis, the data were examined for similarities by coal seam or geographic region. If there were no such similarities, classifications were attempted by combinations of physical and chemical characteristics with pH as the primary factor. Further classification could be made by size composition (expressed as percentage of soil-size particles), total acidity, phosphorus and combinations of these factors.

Evaluation of the data obtained from the laboratory analyses revealed no distinct correlations of either physical or chemical characteristics with inspection district, coal seam being mined or even the depth from which the sample was collected. Thus, no general classification can be made. Summaries of the analyses are shown in Table 12-2 and 12-3. Data from 268 samples were used in the summaries as the remaining 36 samples were from piles containing refuse from two or more different coal seams. Values of pH ranged from a low of 2.0 to a high of 9.4. Values in the very high acid ranges were far more common than in the slightly acid to alkaline ranges. Only 21 samples (7 percent) were pH 6.1 or above. There were 29

(8 percent) in the range pH 4.1 to 6.0, 140 (47 percent) in the range pH 3.1 to 4.0 and 114 (38 percent) were pH 3.0 or less. The other chemical characteristics showed the same wide range of variance.

Table 12-2

Distribution of particle Sizes in Samples of Underground-Mine Refuse (in percent)

Size	Sample	Seam						Pittsburgh
		A	B	C	C'	D	E	
>2"	Average	7	4	5	5	4	5	4
	Median	4	1	0	0	3	4	3
	Highest	19	31	18	34	17	30	20
	Lowest	0	0	0	0	0	0	0
1/4"-2	Average	36	30	25	33	31	35	32
	Median	41	29	28	27	32	33	33
	Highest	54	84	37	65	61	72	59
	Lowest	21	4	9	20	9	12	12
2 mm -1/4"	Average	26	28	27	27	30	27	28
	Median	24	26	30	27	29	26	28
	Highest	43	58	37	37	53	52	43
	Lowest	18	0	19	14	19	6	17
<2 mm	Average	31	37	44	35	35	33	37
	Median	30	37	43	41	36	33	34
	Highest	52	67	57	49	67	62	63
	Lowest	16	1	33	11	9	0	16
Number of samples		10	88	8	16	26	50	70

Source: W. H. Davidson, USDA Forest Service

Northeastern Forest Experiment Station
Kingston, Pa.

Based on the research done by Mr. Davidson and others, it is generally concluded that it is not possible to develop a definitive personality profile of coal waste disposal dumps. However, it is possible to generalize about the overall nature of refuse deposits.

Early refuse deposits were relatively small in volume; however, as mining rates increased, refuse accumulation rates increased. Although mining and coal processing technology improved with increasing coal production quantities, refuse disposal technology did not keep abreast, and as a direct result, coal refuse deposits grew to enormous size without regard to long-term safety or environenvironmental consequences.

Table 12-3

Selected chemical characteristics of samples of underground-mine refuse

Sample	Seam						Pittsburgh
	A	B	C	C'	D	E	
pH							
Average	3.1	3.4	3.0	3.5	3.8	3.8	3.6
Median	2.9	3.2	3.1	3.3	3.6	3.4	3.1
Highest	4.1	6.8	3.4	4.4	6.1	9.4	7.7
Lowest	2.6	2.2	2.4	2.5	3.0	2.4	2.4
Exchangeable acidity (meq H^+/100 g)							
Average	8.5	9.8	6.4	5.1	6.4	8.0	8.8
Median	5.8	7.0	4.4	4.2	6.7	6.5	9.1
Highest	22.2	113.0	15.6	10.5	14.5	39.0	33.4
Lowest	2.3	.6	3.4	2.4	2.4	.4	.3
Conductance (mmho/cm)							
Average	0.87	1.88	1.51	0.32	0.31	1.61	2.30
Median	.75	.61	.64	.21	.22	.86	2.48
Highest	2.23	20.20	5.06	1.30	1.71	8.57	6.75
Lowest	.22	.12	.27	.10	.08	.12	.12
Sulphates (ppm SO_4)							
Average	1,209	3,395	12,097	873	739	4,643	10,953
Median	657	1,087	4,688	788	520	1,050	6,937
Highest	3,227	26,575	50,438	2,000	3,037	30,150	30,150
Lowest	235	62	362	235	37	62	270
Phosphorus (ppm P)							
Average	0.2	1.3	0.6	1.0	1.8	3.1	6.7
Median	.2	.9	.7	1.0	.3	1.4	6.1
Highest	1.0	15.5	1.0	2.2	16.5	16.5	21.0
Lowest	.0	.0	.2	.1	.0	.0	.7
Number of samples	10	88	8	16	26	50	70

Source: W. H. Davidson, ibid

The "calm bank", "slate dump", "refuse dump" or "waste heap" was, in the earliest mining days, simply the easiest spot for random dumping of unwanted material. This "spot" may have been adjacent to the preparation plant, over the nearest hillside or in the nearby stream bed. Various methods have been employed to transport material to the waste dump. Each method was developed to take advantage of the terrain and to apply to the type and quantity of refuse being produced. In most cases it is the characteristics of the refuse that dictate disposal techniques. Disposal, as well as construction, can be viewed as consisting of two operations--conveyance and placement. Coarse refuse is conveyed to the disposal site in a number of ways, including: hauling in trucks over access roads, in cars on rails, on aerial tram systems, on conveyor belts and sometimes combinations of more than one system. At times, coarse refuse is crushed and conveyed in a slurry with fine refuse in pipelines. Fine refuse is almost always conveyed in a slurry through pipelines to a disposal area, normally an impoundment.

The failure to properly allow for and to accordingly plan and engineer these waste sites has caused many of them to become environmental hazards. Disposal practices can be adverse in a number of ways, including: burning coal refuse dumps which pollute the air, contaminated or acid water drainage which will degrade a water course, poor stability characteristics which present a high degree of hazard to life and property downslope from the waste deposit and unsightly waste facilities which cannot be converted to other uses after mining operations have terminated (without inordinate expenditures) offer a serious aesthetic blight. Additionally, these waste deposits usually support little or no vegetation and, therefore, contribute heavily to airborne dust.

12.2.2 Mine Site and Waste Dump Drainage

The potential for contamination of water supplies, both surface and ground water, has been recognized in most mining areas for a considerable time, and some measures to control degradation of waters have been initiated. Potentially the most hazardous threat involving water--the sudden failure of a refuse retaining structure, thus releasing large quantities of contaminants and/or dump volume of flood water and sludge--has, to a large degree, been neglected.

The production of harmful water pollutants from coal mine sites and/or from coal associated strata has been a recognizable fact in the United States for over two hundred and seventy years. In 1689, Gabriel Thomas observed that the colored water flowing from streams in this country was similar to that which flowed from the coal mines in Wales. Water pollutants, such as acid, were being produced before any known coal mines were operating in this country. The coal mining industry has contributed to the increase of pollution by exposing large amounts of sulfide materials that enable the reaction of water, oxygen and sulfur containing materials to form acid.

Mine drainage includes all types of mine water associated with coal mining operations. Mine drainage from coal mine sites may be acid, alkaline or neutral, depending upon the type of rocks or strata the water passes through, the distance it travels and the time it remains in contact with soluble minerals. The drainage may contain a lot of impurities or only a small amount. A substantial amount of mine drainage is neutral or slightly alkaline and contains only minor impurities.

The most difficult type of mine drainage to handle is acid mine drainage. This type of drainage is formed by the reaction of air and water with sulfide minerals present in or associated with the coal bed or refuse pile. By far,

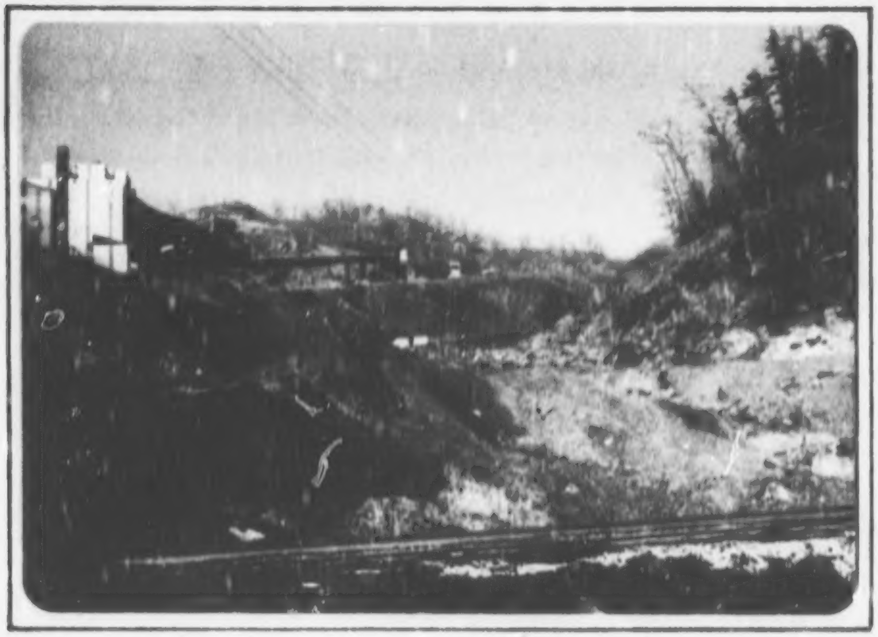
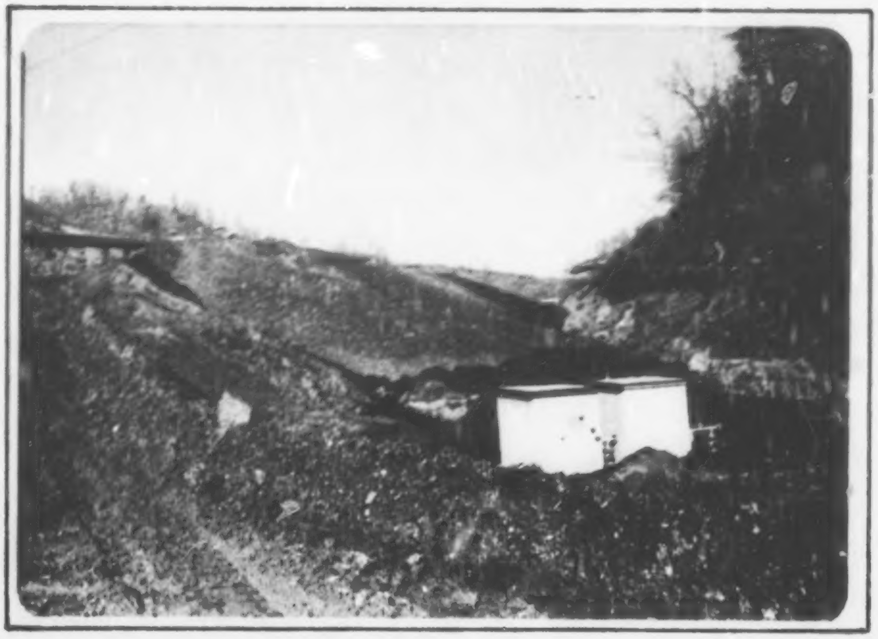


Figure 12-1

Typical Disposal Sites



the most common acid-producing sulfide mineral is iron sulfide, but other sulfide minerals, i.e., copper, zinc or lead (Cu_2S, ZnS or PbS) may be found associated with the deposits.

According to Ronald D. Hill, the exact mechanism of acid mine drainage formation is not fully understood, it is generally believed that pyrite (FeS_2) is oxidized by oxygen (Equation 1) or ferric iron (Equation 5) to produce ferrous sulfate and sulfuric acid.

(1) $\underset{\text{(pyrite)}}{2FeS_2} + 2H_2O + 7O_2 \longrightarrow 2FeSO_4 + 2H_2SO_4$ (ferrous iron + sulfuric acid)

Subsequent oxidation of ferrous sulfate produces ferric sulfate:

(2) $4FeSO_4 + 2H_2SO_4 + O_2 \longrightarrow 2Fe_2(SO_4)_3 + 2H_2O$

The reaction may then proceed to form a ferric hydroxide or basic ferric sulfate and more acid:

(3) $Fe_2(SO_4)_3 + 6H_2O \longrightarrow 2Fe(OH)_3 \downarrow + 3H_2SO_4$

(4) $Fe_2(SO_4)_3 + 2H_2O \longrightarrow 2Fe(OH)\ (SO_4) + H_2SO_4$

Pyrite oxidation by ferric iron

(5) $14Fe^{+++} + FeS_2 + 8H_2O \longrightarrow 15Fe^{++} + 2SO_4^{=} + 16H^{+}$

A low pH water is produced (pH 2-4.5). At these pH levels, the heavy metals such as iron, calcium, magnesium, manganese, copper and zinc are more soluble and enter into the solution to further pollute the water.

The mining and subsequent washing of coal is not a prerequisite to the formation of acid mine drainage; however, coal mining has greatly contributed to the generation of acid drainage. The contribution of coal cleaning to acid mine drainage is tremendous and must not be overlooked, particularly when it may be difficult to classify mine drainage as occurring from an abandoned underground coal mine or from an abandoned coal refuse pile.

Historically, the amount of coal refuse generated annually in the United States has been increasing at an ever greater rate than the amount of raw coal mined. This increase has been continuous since 1930, and is due to two factors: changing mining methods, and increased emphasis upon clean fuels. With the development of mechanized mining techniques and equipment, full seam mining was introduced. Greater quantities of impurities associated with the coal seam could be excavated with the coal, transported to the surface and removed before marketing.

While there have been exceptions where the impurities (refuse, gob) were treated not only with concern for operating convenience over the life of the plant, but also with considerations for eventual abandonment, on the whole, refuse disposal has been rather casual. The result has been the development of many large, undesigned and often poorly constructed coal refuse dumps and impoundments offering an ideal environment for the formation of an acidic drainage containing many suspended solids, dissolved iron and other compounds which may enter the streams and rivers as runoff or seepage. In addition, the continual exposure to the elements causes erosion which in turn offers new material for oxidation which produced more acid, and the resultant environmental contamination cycle.

A full appreciation of the problems of water pollution caused by acid mine drainage requires a basic understanding of occurrences and movement of water in the ground and the modes of ground water entrance into mining areas as well as the characteristics of the entire cover, adjacent mining operations, ad infinitum.

The quality of the water affected by acid mine drainage is variable, but general criteria for the identification of streams with major mine drainage influence are given in Table 12-4. Due to the low pH, the dissolved solids loading may contain significant quantities of iron, aluminum and other heavy metals depending on mineralogical composition of the coal/refuse deposit. The most useful indicator of acid mine drainage presence and concentration is sulfate. Calcium sulfate, the most common neutralization product, is soluble at concentrations usually encountered in receiving streams. The other materials in acid mine drainage tend to precipitate or plate out of solution and are difficult to analyze reliably as the pH and alkalinity of the receiving water change. Because sulfates are usually present in receiving streams in low concentrations and are found in high concentrations in acid mine drainage, the presence of sulfate gives an accurate indication of mine drainage presence.

Table 12-4

CRITERIA FOR DETERMINING ACID MINE DRAINAGE

pH	Less than 6.0
Acidity	Greater than 3 mg/l
Alkalinity	Normally 0
Alkalinity/Acidity	Less than 1.0
Fe	Greater than 0.5 mg/l
SO_4	Greater than 250 mg/l
Total Suspended Solids	Greater than 250 mg/l
Total Dissolved Solids	Greater than 500 mg/l

(After Herricks and Cairns)

The relationship between acid mine drainage intensity and stream-flow is important. Mine drainage volume and discharge intensity have been shown to be seasonally related. The mine drainage volume is dependent on rainfall infiltration to underground areas and refuse piles. Although pyrite oxidation is not appreciably changed by the amount of water present, the concentration of pyritic oxidation end products will vary with volume. Because the infiltration rate is greater during the winter, the volume of discharges is normally increased from December through April. Infiltration decreases during the summer months; thus, mine discharge volumes also decrease.

The major source of acid is pyritic materials located above normal water levels. When the mine or pile is flooded by high base flow (i.e., high infiltration rate) the pyritic oxidation is limited by oxygen transport relationships in the water reducing overall AMD concentrations. If flow through the mine or pile has been low for some time, the oxygen-rich atmosphere allows rapid oxidation of pyrite, and large quantities of oxidation products may be present on unflooded surfaces. As water flow increases, these oxidation products are put into solution. The first flush discharges, caused by high flow, may be highly concentrated.

Superimposed on this pattern of seasonal changes in base flow and AMD concentration are several concentration and stream impact relationships. First, because the first flush discharges may be more concentrated, the assimilative capacity of the stream may be overloaded from sludge loads. Second, the capacity of the receiving stream to assimilate a given acid mine drainage volume and concentration varies with stream drainage and is particularly related to the percentage of base flow represented in the receiving stream, presence of calcareous rocks and several physical factors such as temperature.

Temperature and seasonal climatic conditions affect AMD in other ways. The AMD from underground sources or buried waste piles during the summer months is usually poorly oxidized because oxygen is limited in the mine drainage. The oxidation of this mine drainage in the receiving stream places a severe oxygen stress on the receiving stream. Thus a secondary stress occurs due to the high oxygen demand of the mine drainage which occurs when water temperatures are generally high, and dissolved oxygen is low.

A second seasonally related AMD discharge problem occurs from surface sources. Pyritic materials on gob piles are well oxidized. During the winter months the reduced surface temperature reduces oxidation rates, and temperatures below freezing prevent runoff from the gob piles. The initial melt carries the oxidation products into the receiving stream, but the high assimilative capacity of the stream due to the normal high stream discharge reduces its effect. On the other hand, chemical reactions on the gob piles are increased during the warm summer months. Rainfall during this period usually occurs as high intensity storms which flush unvegetated areas rapidly. The accumulation of pyritic oxidation end products make the initial runoff highly concentrated, and acid mine drainage sludges precede the increased stream flow.

An additional problem associated with the water effluents from the coal cleaning operation and waters draining from the plant site is the quantity of fine coal and refuse materials carried in suspension. These waters are characterized by a heavy concentration of suspended solids and a deep black color. The black color of the coal fines imparts a characteristic (black-water) look to the receiving streams. The suspended solids may settle to the bottom in quiet pools. If the bottom organisms upon which the fish live are covered by these fines, then the coal and refuse fines are detrimental to the water life by destruction of the food supply. In addition, the settled solids can restrict the natural development of water life eggs laid at the bottom of the stream.

12.2.3 Air Contaminants

Literally any substance not normally present in the atmosphere, or measured there in greater than normal concentrations, should be considered an air contaminant. More practically, however, a substance is not labeled as a contaminant until its presence and concentration produce or contribute to the production of some deleterious effect.

The factors that contribute to the creation of an air pollution problem are both natural and man-made. The natural factors are primarily meteorological, sometimes geographical and are generally beyond man's sphere of control, whereas the man-made factors involve the emission of air contaminants in quantities sufficient to produce deleterious effect and are within man's sphere of control. The natural factors that restrict the normal dilution of contaminant emissions include: temperature inversions, which prevent diffusion upwards; very low wind speeds, which do little to move emitted substances away from their points of origin; and geographic terrain, which causes the flow to follow certain patterns and to carry from one area to another whatever the air contains. The man-made factors involve the contaminant emissions resulting from some human activity, e.g., coal preparation.

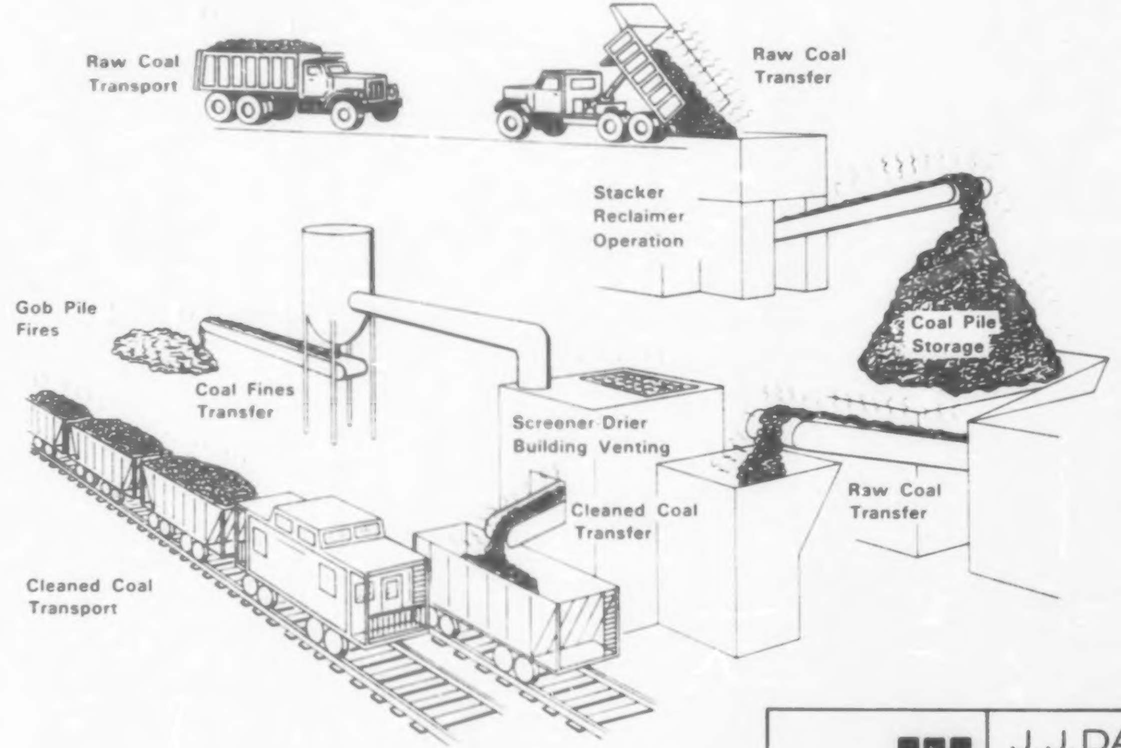
Coal preparation plants were specifically named as major sources of air pollution in 40 CFR Part 52, "Prevention of Significant Air Quality Deterioration", published as proposed in the Federal Register, July 16, 1973. Substances considered air contaminants in and around coal preparation plants fall into two general classes based on their physical state and on their chemical composition. These are:

1) aerosols (particulate matter) and

2) inorganic gases.

12.2.3.1 Aerosols or Particulate Matter Matter dispersed into the atmosphere may be organic or inorganic in composition, and in the liquid or solid physical state. By definition, they must be particles of very small size or they will not remain dispersed in the atmosphere. Among the most common aerosol emissions found from the coal preparation plant site are coal dust, carbon or soot particles; metallic oxides and salts; acid droplets; and silicates and other inorganic dusts.

The non-stack or fugitive emissions from the coal preparation process occur from operations in which the coal or its waste products are stored, transferred or reacted as highlighted in Figure 12-3. The ROM coal is transported (by truck, conveyor or rail car) to the preparation plant. The transport and the subsequent transfer to a storage pile or silo are the first opportunities for fugitive coal and/or road dust emissions. As noted earlier, if the ROM coal is stored in an open pile, it may be subject to wind-blown coal losses. If the pile is dry and the locale is subject to high and frequent winds and pile working, these losses can be serious. Additionally, unless outdoor conveyors and transfer points are enclosed and appropriately controlled, coal being transferred may be a source of wind-blown coal dust.



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Potential Fugitive
Emission Sources

Figure 12-3 DCN

Within the coal cleaning plant, the initial raw coal sizing operations, prewetting operations, some dewatering and mechanical drying operations such as centrifugal drying and the mechanical transportation of the cleaned coal and refuse products may be sources of fugitive emissions. The final transfer of the cleaned coal and refuse products and the storage of those products is also a significant source of aerosol emissions, particularly if the local waste pile should ignite through spontaneous combustion. The final transfer of the cleaned coal to railroad cars, barges or trucks and the subsequent transfer to the user is the last primary opportunity for fugitive emissions from the coal cleaning operation.

In addition to the fugitive aerosol emissions from the general preparation plant site, the largest single source for particulate matter dispersement into the atmosphere is the thermal coal dryer. The emissions from the thermal dryers include combustion products from the coal fired furnace, but these quantities are a small fraction of the particulates entrained by the flue gases passing through the fluidized bed of intermediate and fine sized coal. Emission factors for coal thermal dryers are shown in Table 12-5. The particulates emitted from the coal composition unit consist primarily of carbon, silica, alumina and iron oxides in the fly ash as well as trace quantities of heavy metals. Table 12-6 shows a typical analysis of the heavy metals content of particulates emitted from thermal dryers.

The concern about the trace element content primarily relates to air pollution, but can extend to coal water drainage and, to a lesser extent, to process waters associated with coal preparation plant operations. Despite growing interest, only limited data are available on these

Table 12-5

Particulate Emission Factors for Thermal Coal Dryer[a]

	Uncontrolled emissions[b]	
Type of dryer	lb/ton	kg/MT
Fluidized bed	20	10
Flash	16	8
Multilouvered	25	12.5

[a] Emission factors expressed as units per unit weight of coal dried.

[b] Typical collection efficiencies are: cyclone collectors (product recovery), 70 percent; multiple cyclones (product recovery), 85 percent; water sprays following cyclones, 95 percent; and wet scrubber following cyclones, 99 to 99.9 percent.

Source: EPA Publication AP-42, 2nd Edition

trace metals. The analytical difficulties in such determinations can be formidable and limiting due to the requirements for evaluation at the part-per-billion level.

The range of concentration, quantity and particle size of atmospheric pariculate emission is dependent upon the type of combustion unit in which the coal is burned, the collection device(s) used to reduce particulate emission from the thermal dryer stack and the ash and surface moisture content of the coal being burned.

12.2.3.2 Inorganic Gases constitute the second major group of air contaminants found in and around coal preparation facilities. The inorganic gases generated include the oxides of nitrogen, the oxides of sulfur (primarily SO_2) including sulfuric acid, carbon monoxide and water. All of the inorganic gases are products of the thermal drying operation or burning coal refuse piles.

Table 12-6

Trace Metal Analysis of Particulate Emissions from a Coal Dryer

Element	Concentration ppmw[a]	Element	Concentration ppmw[a]
Be	1	K	1000 to 2000
Cd	50	Ca	3000
As	100	Si	1.5%
V	50	Mg	1000
Mn	50 to 100	Bi	10
Ni	20 to 30	Co	10
Sb	50	Ge	30
Cr	30	Mo	10
Zn	100	Ti	500
Cu	30	Te	100
Pb	30	Zr	10
Se	--	Ba	200
B	10	Al	1.0%
F	--	Cl^-	40 to 118
Li	10	$SO_4^=$	1040 to 3920
Ag	1	Sn	50
Fe	5000	Sr	100
Na	300		

[a] Parts per million by weight

Source: EPA 450/2-74-021a

A number of compounds must be classified as oxides of nitrogen, but only two, nitric oxide (NO) and nitrogen dioxide (NO_2) are important as air contaminants. The first, nitric oxide, is formed through the direct combination of nitrogen and oxygen from the air in the intense heat of any combustion process. The nitric oxide emitted to the atmosphere through the flue gases is then able, in the presence of sunlight, to combine with additional oxygen to form nitrogen dioxide. Usually the concentrations of nitric oxide in the combustion effluents constitute 90 percent or more of the total nitrogen oxides. Nonetheless, since every mole of nitric oxide emitted to the atmosphere has the potential to produce a mole of nitrogen dioxide, one may not be considered without the other. In fact, measurement of their concentrations often provides only a sum of the two reported as the dioxide.

The primary deleterious effects of the oxides of nitrogen relate to the toxicity of the dioxide (such as damage to the lungs), its contribution to photochemical smog and its accompanying sharp odor. Nitrogen dioxide in concentrations of approximately 10 ppm over an 8 hour period can produce lung injury and edema, and in greater concentrations, e.g., 20 to 30 ppm over 8 hours, can produce fatal lung damage.

The air contaminants classified as oxides of sulfur consist essentially of only two compounds, sulfur dioxide (SO_2) and sulfur trioxide (SO_3). The source of both compounds is the combination of atmospheric oxygen with the sulfur in the coal being combusted for the thermal dryers. The total emitted quantities of the sulfur oxides is directly related to the sulfur content of the coal, the type of combustion unit and the amount of excess air used during the combustion process.

Normally, sulfur dioxide is emitted in much greater quantities than sulfur trioxide. Sulfur trioxide is usually only formed under rather unusual conditions and is in fact normally a finely divided aerosol rather than a gas. The primary deleterious effects of the sulfur oxides relate to their toxicity. Both the dioxide and the trioxide are capable of producing illness and lung injury at concentrations as low as 5 to 10 ppm. Further, each can combine with water contained in the flue gases or from the atmosphere to form toxic acid aerosols that can corrode metal surfaces and destroy plant life. Sulfur dioxide by itself also produces a characteristic type of damage to vegetation. In concentrations as small as 5 ppm, sulfur dioxide is an irritant to the eyes and the respiratory system. Both the dioxides and trioxides of sulfur can combine with particles of soot and other aerosols to produce contaminants more toxic than either of the contaminants alone. The combination of the dioxides and trioxides with their acid aerosols have also been found to exert a synergistic effect of their individual toxicities.

12.2.4 Noise

Noise in coal preaparation plants typically results from numerous simultaneous noise sources. Although the noise-producing machinery varies with the plant process and arrangement, the basic noise-generating mechanisms are the same for many different machines. The machinery found in coal cleaning plants may be classified in terms of the basic noise-producing mechanisms, and noise control may be approached in relation to these mechanisms. The primary mechanisms are: impacts, fluid flows and structural vibrations. Impacts of coal on coal or coal on steel dominate in screens, chutes, hammer mills, hoppers and bins; impacts of steel on steel are responsible for the noise of car shakeouts and for the gear noise of crushers. Fluid flow noise emanates from flowers, fans, vacuum pumps, valves and air blasts. Structural vibrations contribute to the noise of screen shaking mechanisms, blowers, gear drives, pumps, centrifugal dryers, conveyors, feeders and the snubbing tanks of vacuum pumps.

Tables 12-7 and 12-8 present a rank-ordering of machinery in terms of need for quieting, taking account of both the noise levels and the worker exposure. All items

Table 12-7

Rank Ordering of Equipment in Terms of Noise Source

RANK	EQUIPMENT	TYPCIAL SOUND LEVEL AT WORKER POSITION dB(A)	TYPCIAL WORKER PROXIMITY
1	Car Shakeout	110-120	2 Workers, Full-Time
2	Screens	95-105	Predominant In-Plant Noise Source; Many Workers, Often Near Full Time
3	Picking Tables	90- 95	1 Worker, Full Time
4	Blowers, Dryers, Air Pumps, Fans, Crushers, Air Valves, Feeders, Flighted Conveyors, Chutes	90-105	Maintenance and Operational Support Workers
5	Motors, Gear Drives, Liquid Pumps, Hoppers	85- 95	Maintenance and Operational Support Workers
6	Belted Conveyors, Deister Tables, Flotation Cells, Water Falls, Rotary Pumps, Heavy Media Vessels, Cyclones	75- 85	Maintenance and Operational Support Workers

Source: Bolt Beranek and Newman, Inc.

Table 12-8

Typical Major Equipment List in a Large Processing Plant and Associated Noise Level dB(A)

EQUIPMENT	NUMBER OF UNITS	TYPCIAL NOISE LEVEL dB(A)
Heavy Media Cyclones	18	80
Crushers	3	100
Rotary Breaker	1	100
Scalping Screens (Shaker Drive)	2	100
Clean Coal Screens (Shaker Drive)	25	95
Refuse Screens (Shaker Drive)	1	100
Centrifugal Dryers	10	95
Disk Filters	8	85
Vacuum Pumps	8	95
Rootes Blowers	4	95
Car Shakeout	1	115
Conveyors (belt)	10	80
Conveyor Drives	10	95
Chutes	36	90
Fans	2	95
Vibrating Feeders	4	90
Tappers or Air Blasts	10	100
Flotation Cells	8	75
Pumps	6	85

Source: Bolt Beranek and Newman, Inc.

except those in the last group (group 6) must be quieted if it is desired to provide a plant noise environment that is below the 8 hour per day allowable 90 dB(a) level.

Most existing statutes governing industrial community noise prescribe maximum permissible A-weighted levels of 50 dB(a) for nighttime (10 p.m. to 7 a.m.) and 55 to 65 dB(a) for daytime, as measured at the boundaries of surrounding residential areas. These values assume that the noise level fluctuates little with time; more stringent restrictions may apply for fluctuating noise levels. Since the noises emanating from coal cleaning plants tend to be essentially non-fluctuating, one may take 50 dB(a) for nighttime and 60 dB(a) for daytime operation--as measured at the community boundary nearest the plant--to be reasonable criteria.

REFERENCES AND/OR ADDITIONAL READING

Akers, David J., Jr.; & Moss, Edward A.; "Dewatering of Mine Drainage Sludge -- Phase II", Office of Research and Monitoring, EPA R2-73-169, February 1973

Altomare, Philip M., "The Application of the Tall Stack and Meteorology in Air Quality Control of SO_2", Coal Utilization Symposium -- Focus on SO_2 Emission Control, Louisville, Kentucky, October, 1974

AMAX Henderson, "An Experiment in Ecology", Editorial Alert - 1974, Mountain Empire Publishing Company

American Public Health Association, American Water Works Association & Water Pollution Control Federation, "Standard Methods for the Examination of Water and Wastewater" (13th Ed.), APHA, Washington, D.C., 1971

Anerson, J.C., "Coal Waste Disposal to Eliminate Tailings Ponds", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Atwood, Genevieve, "The Technical and Economic Feasibility of Underground Disposal Systems", Coal and Environmental Technical Conference, October 1974

Atwood, Genevieve, "The Technical and Economic Feasibility of Underground Disposal Systems", First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 1974

Barnes, H.L. & Romberger, S.B., "Chemical Aspects of Acid Mine Drainage" Western Research Application Center, University of Southern California, #CA-67

Battelle-Columbus, "SO_2 Control: Low-Sulfur Coal Still the Best Way", Power Engineering, November 1973

Bechtel, Inc., "Coal Slurry Pipeline--An Environmental Answer", San Francisco, California

Benza, Stephen T. & Lyon, Ann E., "The Use of Lime, Limestone and Other Carbonate Material in the New Coal Era", NCA/BCR Coal Conference and Expo II, October 1975

Bisselle, C.A.; Haus, S.A.; Lubore, S. H.; Scholl, M.M.; & Wilcox. S.L., "Strategic Environmental Assessment System: Initial Analysis of Environmental Residuals", The Mitre Corporation, February 1973

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Black Sivalls & Bryson, Inc., "Study of Sulfur Recovery from Coal Refuse", U.S. Government Printing Office, September 1971

Bluck, W.V. & Norton, G., "High Intensity Fine Coal Flotation", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Bioko, V.A. Parinskiy, O.P., "Equipment for Dewatering of Coal", Chapter 5 of "Hydraulic Capability for Underground Mining of Coal", Katalog-Spravochnik, Moscow, 1965 (Translated by Terraspace)

Bowen, James B. & Builiani, R.L., "The Integrated Occupational Health Program of the Erie Mining Company", American Mining Congress Convention, Las Vegas, Nevada, October 1974

Bureau of Water Quality Management, "Air and Water Quality Regulations"

Busch, Richard A; Baker, Ronald R.; Atkins, Lynn A., "Physical Property Data on Coal Waste Embankment Materials", U.S. Bureau of Mines RI 7964, 1974

Capp, John D. & Gillmore, Donal W., "Fly Ash From Coal Burning Power Plants" An Aid in Revegitating Coal Mine Refuse and Spoil Banks", Coal and the Environment Technical Conference, October 1974

Capp, John P.; Gilmore, D.W.; Simpson, David G., "Coal Waste Stabilization by Enhanced Water", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Carta, M.; Del Fa. C.; Ciccu, R.; Curreli, L.; Agus, M., "Technical and Economical Problems Connected with the Dry Cleaning of Raw Coal and in Particular With Pyrite Removal by Means of Electrical Separation", Italy, Australian Coal Conference

Carter, R.P.; Wilkey, M.L.; Johnson, D.O.; Kennedy, A.S., "Coal Blending as a Means to Meet Air Emission Standards", NCA/BCR Coal Conference and Expo II, October 1975

Casali, J.T., "Heat Drying Sludge from Ponds", American Mining Congress Coal Convention, May 5-8, 1974

Cassady, Jon M., "Obstacle Course for Permits and Approval", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Cavallaro, J.A.; Deurbrouck, A.W.; Baker, A.F., "Physical Desulfurization of Coal", Alche Symposium Series, Vol. 70, pp. 114-122

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Cavallaro, J.A.; Johnston, M.T.; Deurbrouck, A.W., "Sulfur Reduction Potential of the Coals of the United States", U.S. Bureau of Mines RI 8118

Chedgy, David G., "Reduction of Environmental Noise Levels at the Meadow River No. 1 Preparation Plant", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Chemical Construction Corporation, "The High Sulfur Combustor - A Study of Systems for Coal Refuse Processing", New York, New York, February 1971

Chemical Construction Corporation, "The High Sulfur Combustor--Volume I", National Technical Information Service, Springfield, Virginia, Feburary 1971

Chironis, Nicholas P., "Results of a Noise Control Program at a New Coal Preparation Plant", Coal Age, January 1976

Coal Age, "Multi-Stream Coal Cleaning System Promises Help With Sulfur Problem", January 1976

Coal Research Bureau, "Underground Coal Mining Methods to Abate Water Pollution", West Virginia University, 1970

Colorado School of Mines, "Removal of Sulfur from Coal by Teatment with Hydrogen--Phase I", Research and Development Report #77, Interim Report No. 1

Cook, L., "Practical Application of Hydraulic Mining at Tahui Buller Coalfield", Paper 31, Mining Conference, School of Mines & Metallurgy, University of Otago, May 1953

Cooper, Donald K., "Choosing Closed Circuits for Coal Preparation Plants", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Cooper, Donald K., "Coal Preparation - 1974", Mining Congress Journal, February 1975

Cuffe, Stanley T., et al. "Emissions from Coal-Fired Power Plants", National Technical Information Service, Springfield, Virginia, 1967

Culp-Culp, "Advanced Waste Water Treatment", Van Norsten, 1971

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Cutler, Stanley, "Emissions from Coal-Fired Power Plants", U.S. Department of Health, Education and Welfare, 1976

Dahlstron, D.A.; Silverblatt, C.E., "Dewatering of Pipeline Coal", U.S.A., Australian Coal Conference

Dancy, T.E., "Control of Coke Oven Emissions", AISI Yearbook, p. 181, 1970

Danielson, John A. (Editor), "Air Pollution Engineering Manual (2d Ed.)", U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1973

D'Appolonia, E., "Engineering Criteria for Coal Waste Disposal", Mining Congress Journal, October 1973

Day, James M., "Current Status of Proposed Federal Waste Disposal Rules", Mining Congress Journal, June 1974

Dean, K.C.; Havens, Richard; Glantz, M.W., "Methods and Costs for Stabilizing Fine-Sized Mineral Wastes", U.S. Bureau of Mines RI 7896 1974

Dean, Karl C.; Havens, Richard, "Methods and Costs for Stabilizing Tailings Ponds", Mining Congress Journal, December 1973

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II ", Pennsylvania State University, 1963

Decker, Howard W., Jr.; Hoffman, John N., "Dedusting, Dust Collection and Coal Surface Treatment (Chapter 3)", Coal Preparation, Volume II, Pennsylvania State University, 1963.

Department of Environmental Resources, "Solid Waste Management", State of Pennsylvania

Department of Environmental Resources, "Waste Water Treatment Requirements"; "Industrial Wastes"; "Special Water Pollution Regulations"; "Erosion Control", State of Pennsylvania

Department of Environmental Resources, "Water Quality Criteria", State of Pennsylvania

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Division of American Society Civil Engineering, "Journal of Sanitary Engineering:

Dokunin, A.V.; Onika, D.G., "Hydraulic Underground Mining", Translated for Branch of Bituminous Coal Research, Division of Bituminous Coal, U.S. Bureau of Mines

Doyle, Frank J.; Bhatt, H.G.; Rapp, J.R., "Analysis of Pollution Control Costs", Report prepared for Appalachian Regional Commission and Office of Research and Development of the EPA, EPA 670/2-74-009 February 1974

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Analysis of Pollution Control Costs", EPA 670/2-74-009

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Chemistry & Classification of Mine Drainage", EPA 670/2-74-009, February 1974

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "National Ambient Air Quality Standards", EPA 670/2-74-009, February 1974

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Other Mine Drainage Abatement Procedures", EPA 670/2-74-009, February 1974

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Refuse Bank & Mine Fires", EPA 670/2-74-009, February 1974

Dunnigan, A.R.; Dennis, R.A., "Control System for a Very Wide Range pH Effluent Stream"

Durard, John "Permissible Noise Exposure--Walhealey Tables"

Ellison, Richard D.; Almes, Richard G., "Synopsis of Engineering and Design Manual for Coal Refuse Embankments", Coal and the Environment Technical Conference, October 1974

Ellison, William; Heden, Stanley D.; Kominek, Edward G., "System Reliability and Environmental Impact of SO_2 Processes", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Engdall, R.B., "A Critical Review of Regulations for the Control of Sulfur Oxide Emissions", Battelle Columbus Laboratories, APCA Journal, Vol. 23, #5, May 1973

Environmental Analysis, Inc., "Air Quality in Nassau-Suffolk County, N.Y.", 1972

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Environmental Protection Agency, "Air Pollution Emission Factos", EPA Publications AP-42, April 1973

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Environmental Protection Agency, "Background Information for Standards of Performance: Coal Preparation Plants (Volume I: Proposed Standards)", Emission Standards & Engineering Division, EPA, Research, Triangle Park, North Carolina, October 1974

Environmental Protection Agency, "Background Information for Standards of Performance: Coal Preparation Plants (Volume II: Test Data Summary)", EPA Research Triangle Park, North Carolina, October 1974

Environmental Protection Agency, "Environmental Impact Assessment Guidelines for Selected New Source Industries"

Environmental Protection Agency, "Municipal Sewage Treatment Standards"

Fair, Geyer, and Okun, "Water and Waste Water Engineering", Vol. 2, Wiley and Sons, 1968

Fairhurst, Charles, "European Practice in Underground Stowing of Waste from Active Coal Mines", First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 1974

Falkie, Thomas W., "Overview of Underground Refuse Disposal", First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 1974

Falkie, Thomas W., "Overview of Underground Refuse Disposal", Coal and the Environment Technical Conference, October 1975

Federal Register, "Mineral Resources - Rules and Regulations", Title 30, Chapter 1, Part 77

Federal Register, "Standards of Performance for New Stationary Sources (Coal Preparation Plants)', Volume 39, #207, Part II, EPA, October 24, 1974

Foreman, William E., "Impact of Higher Ecological Costs and Benefits on Surface Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Gayle, J.B.; Eddy, W.H., "Effects of Selected Operating Variables on Continuous-Cell Flotation of Coal: A Lab Study", U.S. Bureau of Mines Report of Investigations #5989

Geer, M.R.; Jacobsen, P.S.; Sokasi, M., "Dewatering Coal Flotation Tailing by the Admixture of Crushed Washery Refuse", U.S. Bureau of Mines Report of Investigations #7110

Gospodarka, Bornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Gregory, M.J., "Problems Associated with Closing Plant Water Circuits", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Greenwald, Edward H., Jr., "A Landscape Architect Looks at Site Planning and Surface Development of Coal Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Grim, E.C.; Hill, R.D., "Environmental Protection in Surface Mining Of Coal", NERC, Cincinnati, Ohio, October 1974, EPA 670/2-74-093

Gvozdek, G.; Macura, L., "Hydraulic Mining in Some Deep Pits in Czechoslovakia", Translated by National Coal Board (A 1683), Uhli #12, December 1958

Hall, A.W.; Martin, J.W.; Stewart, R.F.; Poston, A.M., "Precision Tests of Neutron Sulfur Meter in Coal Preparation Plants", U.S. Bureau of Mines Report of Investigations #8038, 1975

Hand, John W., "Drying of Western Coal",Mining Congress Journal, May 1976

Haskins, J. William, "The Economical Advantages of Drying Coal Fines Using Indirect Heat Exchanging", NCA/BCR Coal Conference and Expo II, October 1975

Henderson, G.S.; Andren, A.W.; Harris, W.F.; Reichle, D.E.; Shugart, H.H.; Van Hook, R.I., "Environmental Assessment of SO_2 and Trace Element Emissions from Coal Utilization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Henderson, James, "Environmental Overkill the Natural Resource Impact", American Mining Congress Convention, October 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Hill, Ronal D., "Water Pollution From Coal Mines", Water Pollution Control Association of Pennsylvania, 45th Annual Conference, 1973

Hoffman, L.; Truett, J.B.; Aresco, S.J., : An Interpretative Compilation of EPA Studies Related to Coal Quality & Cleanability", Mitre Corporation, May 1974 EPA 65012-74-030

Hollinden, Gerald A.; Elder, Henry W., "Worldwide Review of Major Sulfur Dioxide Removal Processes Applicable to Coal-Fired Utility Boilers", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Houle, D.L., "The Effect of Process Design on pH & pIon Control", Eighteenth ISA-AID Symposium, May 3, 1972

Hulett, L.D.; Carter, J.A.; Cook, K.D.; Emery, J.F.; Klein, D.H.; Lyon, W.S.; Nyssen, G.A.; Fulkerson, W.; Bolton, N.E., "Trace Element Measurements at the Coal-Fired Allen Steam Plant--Particle Characterization", COal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky 1974

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Provence Coalfield", France, Australian Coal Conference

Irminger, P.F.; Giberti, R.A., "Desulfurization Technology to Meet the Power Demand", NCA/BCR Coal Conference and Expo II, October 1975

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracity in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Jimeson, R.M.; Spindt, R.S., "Pollution Control and Energy Needs", Advances in Chemistry Series, American Chemical Society, Washington, D.C., 1973

Johakin, J., "Solving the SO_2 Problem--Where We Stand with Application and Costs", Coal Age, May 1975

Journal of the Air Pollution Control Association, "Panel Calls Beneficiation-FGD Combination 'Most Economical, Best All-Around Choice'", November, 1975

Journal of American Water Works Association

Joy Manufacturing Company, "Basic Handbook of Air Pollution Control Equipment", Western Participation Division, 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Kalb, G. William, "The Attainment of Particulate Emission Standards at Fluidized-Bed Termal Coal Dryers", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Kalika, Peter W.; Bartlett, Paul T.; Kenson, Robert E.; Yocum, John E., "Measurement of Fugitive Emissions", 68th Annual APCA Meeting, Boston, Massachusetts, June 1975

Kenson, R.E.; Kalika, P.W.; Yocom, J.E., "Fugitive Emissions from Coal", NCA/BCR Coal Convention and Expo II, October 1975

Kent, James A. (Editor), "Riegel's Handbook of Industrial Chemistry (7th Ed.)", Van Nostrand Reinhild Publishing Company, New York, 1974

Kilgore, James D., "Physical and Chemical Coal Cleaning for Pollution Control", Industrial Environmental Research Laboratory, Environmental Protection Agency, Research Triangle Part, North Carolina

Kodentsov, A.A.; Kurkin, V.F.; Krasnoyarskiy, L.S.; Papkov, M.N., "Dewatering of Coal and Rock, Clarification of Waste Water During Driving by Hydromechanization", Ugol Ukrainy #11 (Translated by Terraspace)

Krebs Engineers, "Brochure and Letter - June 1975"

LaMantia, Charles R.; Raben, Irwin A., "Some Alternatives for SO_2 Control", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Lamonica, J.A., "Noise Levels in Cleaning Plants", Mining Congress Journal, July 1972

Lawrence, William F.; Cockrell, Charles F.; Muter, Richard, "Power Plant Emissions Control", Mining Congress Journal, April 1972

Leavitt, Jack M.; Leckenby, Henry F.; Blackwell, John P.; Montgomery, Thomas L., "Cost Analysis for Development and Implementation of a Meteorologically Scheduled SO_2 Emission Limitation Program for Use by Power Plants in Meeting Ambient Air Quality SO_2 Standards", TVA Air Quality Branch, Marcel Dekker, Inc., 1974

Leonare, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Leven, P., "Pumping: A Good Way to Dispose of Coal Plant Refuse", Coal Mining and Processing, June 1966

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Lewis, Clifford J., "Development of a Rotating Stack Gas Scrubber", NCA/BCR Coal Conference and Expo II, October 1975

Lombardo, J.L., "State-of-the-Art--Acid Mine Drainage Control", American Mining Congress Mining Convention/Environmental Show, Denver, Colorado, September 1973

Lowman, Stephen G., "Westmoreland Coal's Bullitt Plant Upgrades Steam COal Quality", Coal Age, 1973

Lownie H.W. et al., "A Systems Analysis Study of the Integrated Iron and Steel Industry", EPA Project PH-22-68-65 Report

Lowry, H.H. (Editor), "Chemistry of Coal Utilization", John Wiley & Sons, Inc., New York, New York, 1963

Lovell, Harold L., "Sulfur Reduction Technologies in Coals by Mechanical Beneficiation (3d Draft)", Commerce Technical Advisory Board Panel on SO_2 Control Technologies, March 1975

Luckie, Peter T.; Draeger, Ernie A., "The Very Special Considerations Involved in Thermal Drying of Western Region Coals", Coal Age, January 1976

Magee, E.M. et al., "Evaluation of Pollution Control in Fossil Fuel Conversion Processes; Gassification; Sectional: Koppers-Totzek Process", EPA Project 69-02-0629

Magee; Hall; Varga, "Potential Pollutants In Fossil Fuels", Environmental Protection Technology Series, ESSO Research & Engineering Company, June 1973

Magnuson, Malcolm O.; Baker, Eugene C., "State-of-the-Art in Extinguishing Refuse Pile Fires", Coal and the Environment Technical Conference, October 1974

Maneval, David R., "Assessment of Latest Technology in Coal Refuse Pile Fire Extinguishment", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Manzual, David R.; Lemezis, Sylvester, "Multistage Flash Evaporation Systems for the Purification of Acid Mine Drainage", SME/AIME Translations, Vol. 252

Margolf, Charles W., "Public Information--Industrial Involvement", American Mining Congress Coal Show, Detroit, Michigan, May 1976

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Markley, R.W.; Cavallaro, J.A., "Efficiency in Cleaning Fine Coal by Froth Flotation--A Cell by Cell Pilot Plant Evaluation", Mining Congress Journal, June 1974

Martin, John F., "Quality of Effluents from Coal Refuse Piles", Coal and the Environment Technical Conference, October 1974

Mathur, S.P., "Hydraulic Mining of Coal", Journal of Mines, Metals and Fuels, May 1972

McCormack, Donald E., "Soil Reconstruction: Selecting Materials for Surface Placement in Surface-Mine Reclamation", American Mining Congress Coal Show, Detroit, Michigan, May 1976

McGauey, "Engineering Management of Water Quality", McGraw-Hill, 1968

McNally-Pittsburg Manufacturing Corporation, "Coal Preparation Manual #572", Extensive Analysis on McNally Pittsburg Coal Cleaning Technology

McNally-Pittsburg Manufacturing Corporation, "A Study of Design and Cost Analysis of a Prototype Coal Cleaning Plant", Department of Health, Education and Welfare Contract PH 22-68-59

Mengelers, J.; Absil, J.H., "Cleaning Coal to Zero in Heavy Medium Cyclones", Coal Mining and Processing, May 1976

Metcalf & Eddy Inc., "Waste Water Engineering, Collection-Treatment-Disposal", McGraw-Hill

Meyers, Sheldon, "The Development of Coal Resources and the Environmental Impact Statement", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Mill, Ronald, "Control & Prevention of Mine Drainage", Battelle Conference 72, November 1972

Miller, David W., "Toxic Standards for Water Pollution", American Mining Congress Convention, October 1974

Miller, F.; Wilson, E.B., "Coal Dewatering - Some Technical and Economic Considerations", American Mining Congress Coal Convention, May 5-8, 1974

Miller, R.E.; Agarwal, J.G.; Petrovic, L.J., "Economic & Technical Considerations in the Use of Coal as Clean Fuel", American Mining Congress Convention, May 6-9, 1973

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Montgomery, T.L.; Frey, J.W., "Tall Stacks and Intermittent Control of SO_2 Emissions TVA Experience and Plans", American Mining Congress Convention, October 1974

Morris, George J., "Reclaiming Coal from Refuse Ponds", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Moss, E.A.; Akens, D.J., Jr., "Dewatering of Mine Drainage Sludge", EPA R2-73-169, February 1973

Moulton, Lyle K.; Anderson, David A.; Hussain, S.M.; Seals, Roger K., "Coal Mine Refuse: An Engineering Manual", Coal and the Environment Technical Conference, October 1974

Nalapko, I.A.; Shevchenko, I.A.; Manza, P.I., "Industrial Tests of a Plant Unit for the Extinction and Transportation of Slag and Ash"

Nalco Chemical Company, "Brochure and Letter - 1975"

National Coal Association, "National Ambient Air Quality Standards--Environmental Protection Agency"

National Coal Association, "Coal Utilization Symposium--Focus on SO_2 Emission Control", Coal and the Environment Technical Conference October 1974

National Coal Association, "First Symposium on Mine & Preparation Plant Refuse Disposal", Coal and the Environment Technical Conference, October 1974

National Coal Association, "Second Symposium on Coal Utilization", NCA/BCR Coal Conference and Expo II, October 1975

National Coal Board, "Exploratory Trails in Hydraulic Mining at Trelewis Drift Mine", September 1961

National Coal Board, "Hydraulic Transport of Coal at Woodend Colliery", September 1961

Nunenkamp, David C., "Survey of Coal Preparation Techniques for Hydraulically Mined Coal", Published for Terraspace Inc., July 1976

O'Brien, Brice, "Environmental Protection", Mining Congress Journal, February 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

O'Brien, Ellis J.; Walker, Joseph L., "Environmental and Processing Innovations--Bullitt Preparation Plant", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1973

Ottmers, Delbert M.; Phillips, James L.; Sipes, Teresa G., "Factors Affecting the Application of Flue Gas Desulfurization Systems to Gas- and Oil-Fired Power Plants Being Converted to Coal-Fired Units", NCA/BCR Coal Conference and Expo II, October 1975

Padgett, Joseph, "Sulfates--Recent Findings and Policy Implications", NCA/BCR Coal Conference and Expo II, October 1975

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

Peluso, Robert G., "A Federal View of the Coal Waste Disposal Problem", Mining Congress Journal, January 1974

Peterson, Gerald, "Noise Control in Coal Preparation Plants", Mining Congress Journal, January 1974

Poland, "Beneficiation of Coal Fines by Selective Flocculation", Australian Coal Conference

Pollution Engineering Magazine, "Applying Air Pollution Control Equipment", Environmental Handbook Series

Pollution Engineering Magazine, "Industrial Solid Waste Disposal", Environmental Handbook Series

Pritchard, David T., "Closed Circuit Preparation Plants and Silt Ponds", Mining Congress Journal, November 1974

Quig, Robert H., "Chemico Experience for SO_2 Emission Control on Coal-Fired Boilers", Coal Utilization Symposium--Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Richardson, James K., "Improving the Public Image of the Mining Industry", American Mining Congress Convention, October 1974

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant", January 1973

Rubin, E.S.; MacMichael, F.C., "Impact of Regulations on Coal Conversion Plants", Environmental Science & Technology, 9, 112, 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Sage, W.L., "Combustion Tests on a Specially Processed Low-Ash, Low-Sulfur Coal", National Technical Information Service, Springfield, Virginia, 1964

Sableski, Joseph J., Jr.; Sedman, Charles B.; Jones, Larry G., "Development of Standards of Performance for New Coal Preparation Plants", Mining Congress Journal, October 1972

Schaeffer, Stratton C.; Jones, John W., "Coal Preparation vs. Stack Gas Scrubbing to Meet SO_2 Emission Regulations", NCA/BCR Coal Conference and Expo II, October 1975

Scott, R.B.; Hill, R.D.; Wilmoth, R.C., "Cost of Reclamation & Mine Drainage Abatement, Elkins Demonstration Project", Federal Water Quality Administration Publication #14010

Seibel, Richard J., "Dust Control at a Transfer Point Using Foam and Water Sprays", U.S. Bureau of Mines Respirable Dust Program Technical Progress Report, May 1976

Sittig, Marshall, "Environmental Sources and Emissions Handbook", Noyes Data Corporation, Park Ridge, New Jersey, 1975

Soderberg, H.E., "Environmental Energy & Economic Considerations in Particulate Control", American Mining Congress Coal Convention, May 5-8, 1974

Sorrell, Shawn T., "Establishing Vegetation on Acidic Coal Refuse Materials Without Use of a Topsoil Cover", Coal and the Environment Technical Conference, October 1974

Stanin, S. Anthony, "Influence of Coal Waste Disposal Regulations", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Stefanko, Robert; Ramani, R.V.; Chopra, Ish Kumar, "The Influence of Mining Techniques on Size Consist and Washability Characteristics of Coal", National Technical Information Service, Springfield, Virginia, August 1973

Stoev, St.; Krasteva, K., "Coal Preparation by Reverse Stratification", Bulgaria, Australian Coal Conference

Terchick, A.A.; King, D.T.; Anderson, J.C.,"Application and Utilization of the Enviro-Clear Thickener in a U.S. Steel Coal Preparation Plant", Transactions of the SME, Volume 258, June 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Tompos, E., "Detailed Investigation of Pyrites Distribution, Taking Account of the Petrographic Components of Coal, with a View to Reducing the Pyrites Content in Coking Coal", Hungary, Australian Coal Conference

Tyrea, P.O.; Anderson, M.M., "Pilot Studies in Wet Dust Control", Mining Congress Journal, September 1973

Ungar, Fax, Patterson, Fox, "Coal Cleaning Plant Noise and Its Control", Bolt, Beranek & Newman, Inc., U.S. Bureau of Mines Contract No. H0133027

U.S. Bureau of Mines, "Clean Energy from Coal Technology", Overview of Coal/Energy Usage, U.S. Government Printing Office, 1974

U.S. Bureau of Mines, "Coal--Bituminous and Lignite in 1973", Division of Fossil Fuels, U.S. Department of Interior Mineral Industry SUrveys, January 1975

U.S. Bureau of Mines, "Implications of the Water Pollution Control Act of 1972 for the Mineral Resource Industry: A Survey", Interdisciplinary Research Task Force Committee, 1975

Wahler, William A., "Coal Refuse Regulations, Standards, Criteria and Guidelines", Coal and the Environment Technical Conference, October 1974

Warnke, W.E., "Latest Progress in Sulfur, Moisture and Ash Reduction Coal Preparation Technology", American Mining Congress Coal Convention, Detroit, Michigan, May 1976

Yancey, J.F.; Geer, M.R., "Behavior of Clays Associated with Low-Rank Coals in Coal-Cleaning Processes", U.S. Bureau of Mines Report of Investigations #5961

Yenovsky, A.Z.; Remesnilsov, I.D., "Thermomagnetic Method of Concentrating and Desulfurizing Coal"

Yusa, M.; Syzuki, H.; Tanaka, S.; Igarashi, C., "Slude Treatment Using a New Dehydrator", Japan, Australian Coal Conference

13. CONTROL OF POTENTIAL POLLUTANTS

13.1 INTRODUCTION

Each class of pollutant (as identified in Chapter 12, Potential Pollutants) may include many different compounds, emanate from several different site sources and contribute in varying degrees to the overall pollution problem. The control and/or disposal of each class of pollutants is equally interrelated even to the point that one control technique may in itself serve as a primary source for some other form of pollution.

The largest single source of potential pollutants from the coal preparation process is the solid refuse. With the possible exceptions of airborne coal dust and the particulate and gaseous emissions from the thermal drying process, and of course noise, solid coal refuse is the principal source of all pollution emanating from a coal preparation site. Accordingly, this chapter is broken down into three general areas:

- Refuse disposal and pollution control technology,
- Air pollution control and
- Noise control.

13.2 REFUSE DISPOSAL AND POLLUTION CONTROL TECHNOLOGY

The amount of coal refuse generated annually in the United States has been increasing at an even greater rate

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than the amount of raw coal mined. This increase has been continuous since 1930, and is due to two factors: changing mining methods and increased emphasis upon clean fuels.

As stated previously in this manual, prior to the early 1920's, when the mechanization of underground mining began, only the thicker and more productive seams were developed; and the coal was mined, picked and loaded underground by hand. During this hand loading process, coal and refuse were usually separated underground and the reject materials were permanently stored in worked out portions of the mine. As a result, with few exceptions, only marketable coal was transported to the surface.

With the development of mechanized mining techniques and equipment, full seam mining was introduced. Greater quantities of impurities associated with the coal seam were excavated with the coal, transported to the surface and removed from the coal before marketing. Since this material has no immediate use, it is usually disposed of as economically as possible, and in such a manner that the disposal does not interfere with the overall mining operations.

The quantity of coal refuse generated in 1969 exceeded 100 million tons for the first time. Estimates are that by 1980 the reject ratio may reach as high as 40% of the total coal mined; i.e., the total annual amount of coal waste generated will be in excess of 200 million tons. This is a conservative estimate, based on a reject ratio of 40% of the total production of 500 million tons. However, the dynamics of the production estimates are very volatile due to the distorted energy situation in the 1970's, and as noted earlier, current estimates are that coal production will reach one billion tons per year shortly before 1985. Such production could mean that the amount of coal refuse would be as much as 400 million tons per year.

There are basically three types of refuse material involved in the disposal process: mine development refuse, coarse preparation plant refuse and fine preparation plant refuse. The mine development refuse contributes a relatively minor amount of the total disposal volume but is significant because of the difference in the materials and characteristics. Coarse refuse considered herein is a product of the preparation plant during the cleaning or benefication of the run-of-mine coal. Coarse refuse is generally removed by mechanical screening, although hand picking, heavy medium processes and cyclones are also utilized for the separating operation. The actual size of the coarse refuse will vary with the preparation plant process, but is generally larger than ½ inch. Some coal operations with large amounts of shale partings included in the coal seam will have coarse refuse in varying amounts in the +4 inch range.

The term "washing the coal" generally refers to a heavy medium separation plant, where a differential specific gravity separation is achieved based upon the creation of an artificially high specific gravity through the use of a dense medium. Ground magnetite or sand usually serves as the heavy medium material. The crushed coal is introduced into a heavy media vessel and the specific gravity of the contained slurry is controlled to allow the lighter coal to float to the surface of the vessel. The refuse fractions (usually the shale and sandstone) are heavier than the contained coal and settle to the bottom of the vessel where a mechanical arrangement allows its removal for reporting to the coarse refuse handling system. Since the heavy media material is a high cost item, both the coarse refuse fractions and the clean coal fractions are rinsed to remove the finely ground particles adhering to them. The heavy media material is then removed from the wash water (using magnetic separation devices in the case of magnetite) for recycling to the cleaning circuit.

As indicated, the fine refuse is developed at various points in the coal cleaning process depending on the benefication method utilized. For example, the wash water from the heavy media recovery system contains fine particles of coal, silica, shale and other materials and must be clarified before the water is returned to the plant process reservoir or released from the plant.

The primary generators of fine coal refuse are:

- wet screen processes,
- dense media washing systems,
- fine coal circuit, i.e., froth flotation and
- dewatering systems.

Coarse refuse material is transported by a variety of materials handling systems, singly and in combination with others. A listing of the systems would include:

- aerial tram,
- conveyors, both belt and metal pan,
- trucks, both end and bottom dump,
- side dump mine cars,
- scrappers and
- bulldozers.

As with mine development refuse, the majority of operators in the past have transported and placed coarse refuse under controlled conditions. Little or no attention was given to effective compaction or other inplace density control methods. Water content depended upon that which came from the plant, along with additions or deletions from the dump surface in conjunction with current weather conditions.

When controlled placement of coarse refuse is in effect, the materials handling system might include modifications such as intentionally routing the trucks to all areas of the dump in order to achieve some surface compaction, or the utilization of conventional compactors and rollers. When this is done, however, construction control techniques predominate over the density or related technical control procedures, resulting in an improved but not necessarily quality controlled structure.

The placement of fine coal refuse has almost exclusively been through hydraulic methods, that is, a slurry pumped from the preparation plant to a settling pound. When the settlement pound is the final disposal site for the fine refuse, control of the placement consists of varying the location of the discharge of the pipeline since the coarser particles will settle closer to the discharge point and the fine particles will settle further away where the ponding of water is occurring. The effect of the point of discharge, with the result in size segregation, can be of significant importance to the stability of an impoundment. In recent years, incised ponds adjacent to the preparation plant have been utilized for plant water clarification, particularly where process equipment such as thickeners can perform the primary solids removal work. These ponds are usually of smaller volume than the conventional refuse embankment impoundments, and must be cleaned periodically of the settled solids. This method requires an excavator, either a drag line or a front end loader, to load the settled materials onto trucks for haulage to the final disposal site. The treatment or utilization of the fine materials at the dump or embankment depends upon the method of construction in use at the site.

A disposal site is a geographical location of a past or present refuse product unit, or units, such as mine or plant, along with the associated refuse disposal deposits. A disposal area is part of a site and is that general area or plot of land which is used for long term storage or disposal and consists of a dump, or impoundment, or a combination of dumps and impoundments. The basic difference between a dump and an impoundment is that, while both are long term accumulations of mine or plant refuse materials on or in the earth, a dump is not capable of impounding liquids and an impoundment is capable of impounding liquids. An impoundment includes three elements: the retaining elements such as the embankment, a depression, etc., and the element of retention capability created by storage space available to retain liquids (unused storage capacity). A disposal site may have more than one disposal area.

Until recently, coal refuse disposal in the United States has not been the object of appreciable industry, government or private interest over the years. The results of the literature search for this work has indicated the paucity of materials that exist of the subject. The textbook and industry reference manuals, while exceedingly specific on other aspects of the coal preparation disciplines, are either lacking completely or woefully deficient in their coverage and treatment of the refuse disposal problem. In the early 1950's when most Appalachian states began to enact and enforce stream pollution control legislation, the coal preparation plants were faced with finding an economical method of complying with the new laws. Previous to this time, the majority of the plants had disposed of their coarse refuse on dumps generally referred to as slate dumps. The plant water was usually allowed to enter the streams with a minimum of clarification. In attempting to find the least expensive way to clarify the plant waters and sludge which oftentimes previously had gone directly into the nearest stream, the coal industry adopted the practice of using coarse mine refuse to construct impoundments in which water clarification could be accomplished. Although the coarse fractions of the fine refuse were removed by the sedimentation in the ponds, along with some of the other finer fractions, the finest material was removed by the process of filtration as the water seeped through the coarse slate dump dams. Since the basic objectives of the water clarifications system thus developed was to filter the plant water by passing it through their dams, little or no attempt was made to control the flow of water over or around the retaining structure. The coarse refuse dumps which were not useful directly as impoundment embankments were often converted into filtration structures and were allowed to continue to grow in size as coal refuse accumulated.

When the coal refuse dump on the Middle Fork of Buffalo Creek failed, the coal industry, with assist from the concerned government and citizens groups, had to take stock of its solid refuse disposal and water clarification problems. In the years between February 1972 and February 1975, it is highly probable that more stability investigation of coal refuse dumps and impoundments were conducted by engineering personnel than in the entire previous history of the American coal industry.

The probability of the refuse deposit failures and the magnitude of the consequences of such failures have increased dramatically in recent years as a result of several factors, the most important of which are:

- changing practices in waste water disposal,
- finer materials resulting from changing mining and coal preparation practices,
- larger and higher disposal embankments,
- more rapid refuse material accumulation resulting from processing coal from several mines in a single preparation plant,
- more rapid refuse material accumulation resulting from accelerated mining rates,
- degradation of refuse materials due to chemical alteration, mechanical breakdown and weathering processes, and
- increased habitation of immediately hazardous or potentially hazardous areas resulting from more intensive domestic utilization in mine areas, as well as the increase of mining operations in inhabited areas.

13.2.1 Refuse Disposal Versus Constructed Embankments

Disposal practices can be environmentally adverse in a number of ways, including burning coal refuse dumps which pollute the air, contaminated or acid water drainage which will degrade a water course, poor stability characteristics which present a hazard to life and property downslope from the waste deposit and unsightly waste facilities which cannot be converted to other uses after mining operations have terminated, without inordinate expenditure.

The potential for contamination for water supplies, both surface and ground water, has been recognized in most mining areas for a considerable time, and some measures to control degradation of waters are widespread. But the potentially most hazardous threat involving water--the sudden failure of a refuse retaining structure, releasing large quantities of contaminants or a flood of water and sludge--has to a large degree been neglected.

As a direct result of these factors, disposal of coal refuse products is now taking a new meaning due to federal and state safety and environmental regulations. In order to assure safety and environmentally suitable disposal of refuse, the dumps and impoundments will have to involve careful planning, design and construction as well as dumping. Where material is deposited on a steep hillside all of the material to be disposed of will have to be placed in such a manner as to be stable; the entire deposit will have to be designed and constructed so that all of the material placed is stable. Where a long and wide valley is available for disposal use, it may be possible to properly construct a relatively small retaining structure, of carefully placed and compacted refuse material which will then retain large amounts of material dumped behind it. Thus, what would usually be a dam if water were stored behind it can become a retaining structure where dry material is stored. If site conditions permit and the project is properly planned, the more expensive construction can be limited to a small part of the total disposal effort and the majority of the material can be dumped with few, if any, stability or environmental problems.

Dumping is a term that means disposal with little effort being expended after waste material is removed from its conveyance, other than perhaps spreading to best utilize the space reserved for its disposal and to facilitate transport and dumping of subsequent loads. Construction, on the other hand, means careful placement, compaction and material selection so as to develop a structurally stable unit--stable unto itself or stable as a retaining structure to retain or support other material deposited behind it.

In addition to being required by law, other incentives for developing properly constructed refuse disposal facilities exist. Technology exists today from the soil mechanics and engineering geology fields, as applied in earth dam design and construction, to properly develop safe and suitable refuse deposits. This technology only needs to be applied to mine refuse disposal to construct environmentally acceptable refuse deposits with minimal hazards. In addition, considerations such as improved land use (including upgrading in some cases) may provide counterbalancing assets which might offset some of the additional development costs by reducing the potential liability which would directly reduce insurance costs and eliminate the possibility of lawsuits while at the same time reducing maintenance and work interruption costs. Contrast a "dump disposal" operation (Figure 13-1) with a planned coal refuse site (Figure 13-2) which is constructed according to methods and techniques well known to the soil mechanics and earth dam engineering community--The planned disposal site has a good appearance and displays characteristics of planning and management. When the mining operation terminates, abandonment procedures are complete and the site will remain environmentally acceptable. The preplanned site has a very low hazard potential and, in many cases, is available for other uses including agriculture and recreation. The properly built refuse deposit is not susceptible to combustion nor does it contribute significantly to water supply degradation.

The development of an effective, economic and environmentally acceptable refuse disposal system cannot rely upon chance or accidental design. Rather, it must be

Figure 13-1
Specific Gravity Results for Fine Coal Refuse

Figure 13-2
Common Characteristics - Coarse Coal Refuse

the result of systematic development and compilation of data and information utilized in a refined engineering effort to develop an overall plan to encompass the life of the disposal facility from original construction through operation and maintenance to final abandonment.

The basic data required for a decision to open or reactivate a mine are usually coal seam and coal market data. If the mining company has the coal reserves available to meet a given set of market conditions (the physical and chemical composition of the coal product along with the basic price information), the approval is given to prepare an economic and engineering study of the proposed mining operation. Once a mining method and preparation plant process, which together satisfy the basic coal seam and coal market data, have been adopted, initial refuse production estimates can be made concerning the size range, the qualities and the quantities of the various sizes which will be produced. Since the size range of the refuse material will have a controlling influence on the type of disposal facility that can be utilized for effective long term storage, a site availability study with this as its prime datum should be inititated. For example, if large amounts of plant water with suspended solids are to be produced, a large cross-valley impoundment may be the best type of disposal facility for this type of refuse product, but a suitable site for such an impoundment may not be available.

The site availability study would include considerations of both underground as well as surface refuse disposal sites. Modern day land values and the consequences of environmental impact should not be overlooked when evaluating underground sites, even though the engineering and operating restrictions may appear to be greater. The disposal system capacity requirements should be treated somewhat separately from the disposal type selection in order to define what amounts of the various size ranges might best be adequately handled together or, conversely, which should be handled separately. As in the cross-valley site mentioned above for large volumes of plant water with suspended solids, perhaps there are also significant quantities of coarse refuse which if placed in the cross-valley fill area might utilize too much of the disposal capacity of that site and would, therefore, be better handled at another site.

The site availability studies should be used as an interactive feedback to the preparation plant process, assuming the coal seam and coal market data permit modifications to the plant flow sheet, through the mining method selection to consider any feasible alternatives, and back again to the disposal size and capacity requirements for another disposal site type selection. This process can iterate as many times as the project evaluator feels are economically fruitful, but in most cases, the number of available sites will serve to govern the number of evaluations that can be performed.

Once a disposal site (or sites) has been selected and the type of refuse deposit determined, selection of the materials handling system can proceed. While this may seem to be primarily an economic analysis to achieve the lowest combined capital and operating costs, the impact of the materials handling system on the engineering properties of the deposited refuse material cannot be overlooked. These properties can be significantly affected by the selection of a particular method of materials handling, or by the particular manner in which a materials handling system is operated. For example, for many years coal refuse has been dumped from aerial trams with no recognition of the potential influence on engineering properties of refuse materials, such as stratification and permeability, by the method being used. The addition of bulldozers and compactors to the handling system in order to develop a more acceptable end result, may make the aerial tram system acceptable to a given set of site and operating conditions, even though the improvement will result in an addition to the capital and operating costs.

The final step in the disposal system requirements development is an economic consideration of the overall system configuration. If the economics appear to be unrealistic or unattainable for a given project, reason dictates a recycling through the mining method selection phase to achieve, if possible, an economically acceptable disposal system. Figures 13-3 and 13-4 are flow charts of a Refuse Disposal Systems Development Procedure.

13.2.2 Refuse Disposal Site Selection Criteria

Site investigations must consider the effect of refuse disposal practices on all environmental factors, not only factors which might be affected by catastrophic embankment failure. The primary environmental factors to be considered are water quality, air quality, sedimentation, erosion, fish and wildlife, forestry and general aesthetics. These factors should all be considered at an early stage during the investigation, so that environmentally poor sites do not receive undue emphasis. It is important that all of these factors be considered together with equal weight, at least in the general overview. Unless an overall perspective is maintained, there is a tendency to give one or two environmental factors unbalanced weight at the expense of others. This environmental perspective must also include real-world socio-economic factors so that a

REFUSE DISPOSAL SYSTEM DEVELOPMENT FLOW CHART

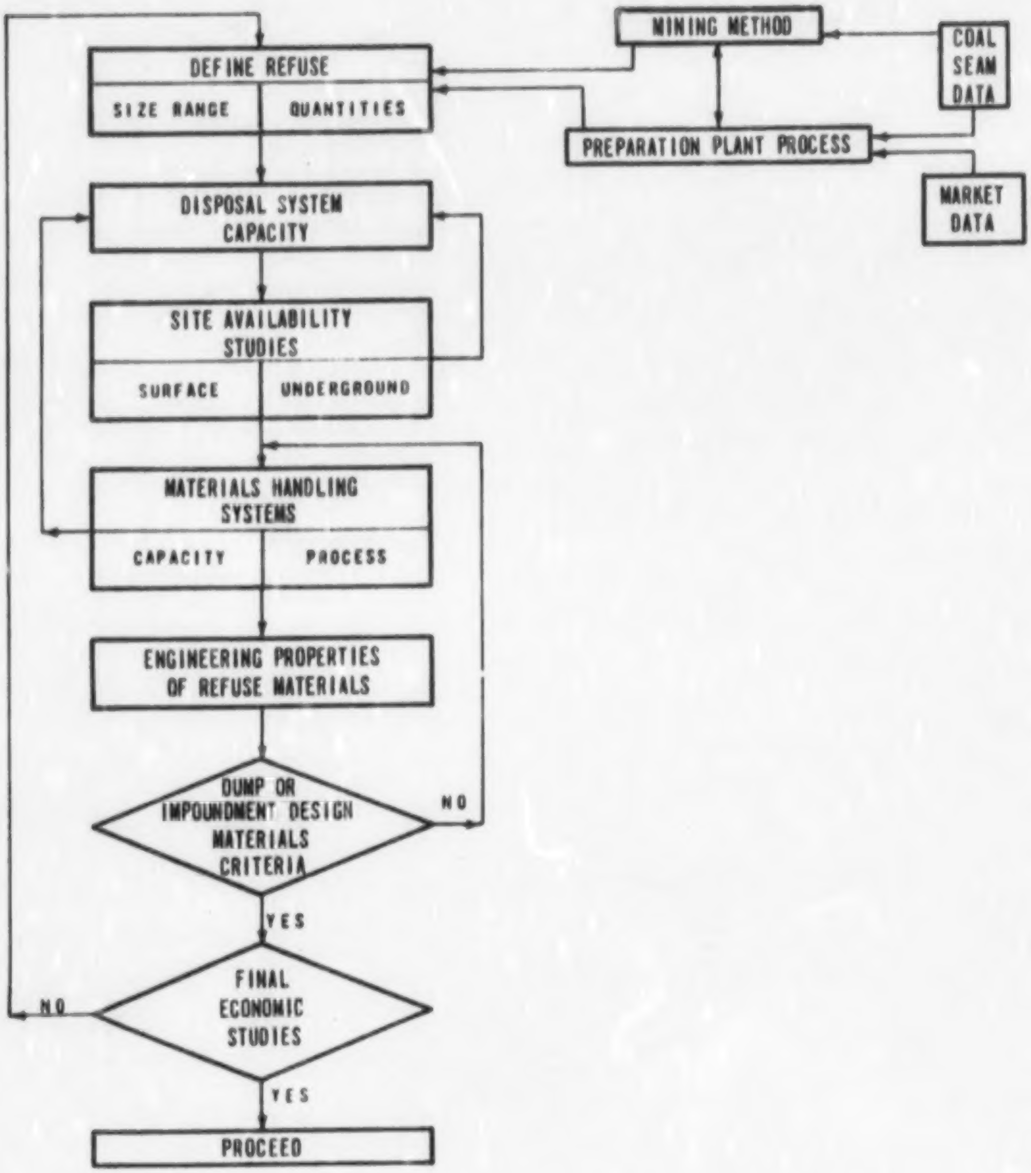


Figure 13-3

REFUSE DISPOSAL SYSTEM DEVELOPMENT FLOW CHART

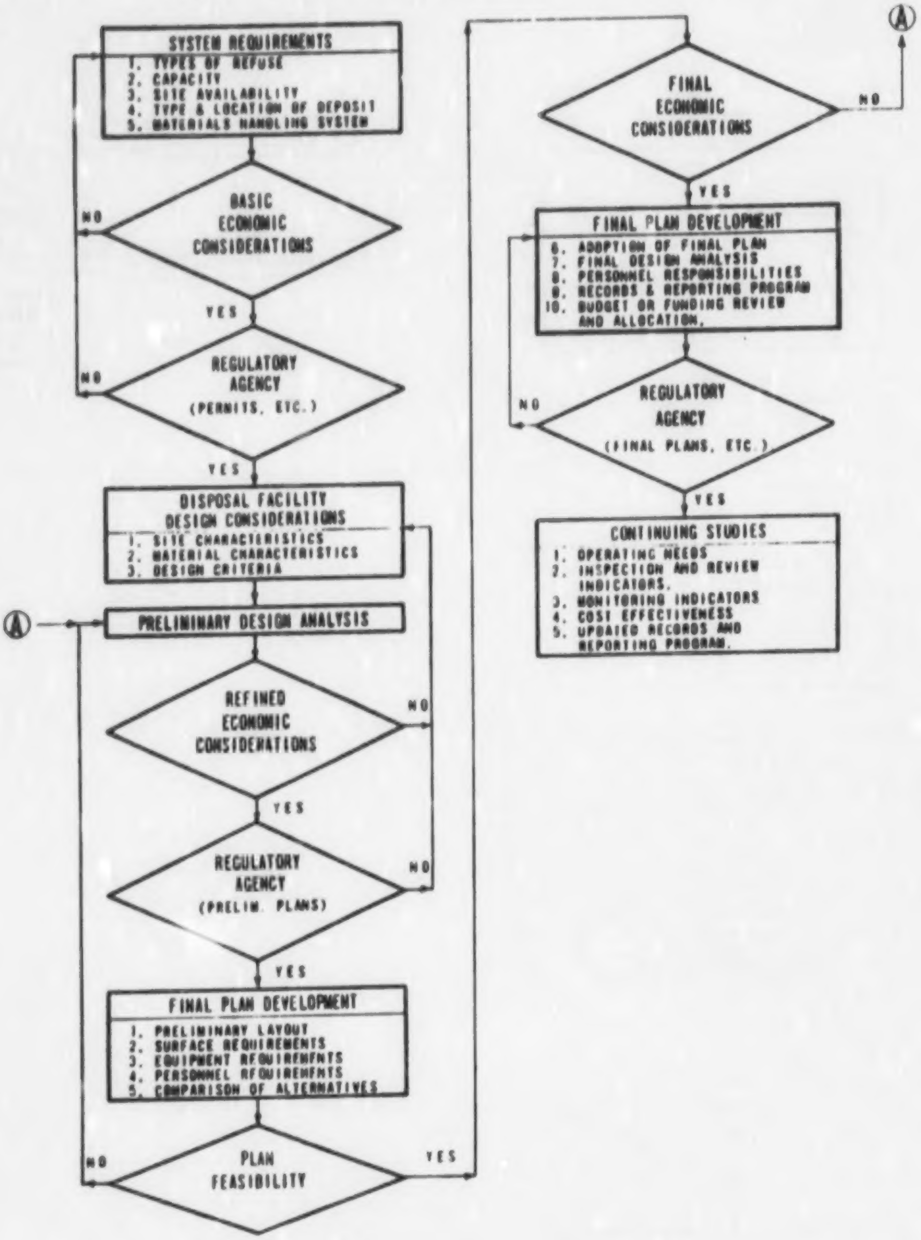

SYSTEM REQUIREMENTS
1. TYPES OF REFUSE
2. CAPACITY
3. SITE AVAILABILITY
4. TYPE & LOCATION OF DEPOSIT
5. MATERIALS HANDLING SYSTEM
BASIC ECONOMIC CONSIDERATIONS
NO
YES
REGULATORY AGENCY (PERMITS, ETC.)
NO
YES
DISPOSAL FACILITY DESIGN CONSIDERATIONS
1. SITE CHARACTERISTICS
2. MATERIAL CHARACTERISTICS
3. DESIGN CRITERIA
A
PRELIMINARY DESIGN ANALYSIS
REFINED ECONOMIC CONSIDERATIONS
NO
YES
REGULATORY AGENCY (PRELIM. PLANS)
NO
YES
FINAL PLAN DEVELOPMENT
1. PRELIMINARY LAYOUT
2. SURFACE REQUIREMENTS
3. EQUIPMENT REQUIREMENTS
4. PERSONNEL REQUIREMENTS
5. COMPARISON OF ALTERNATIVES
NO
PLAN FEASIBILITY
YES
FINAL ECONOMIC CONSIDERATIONS
NO
A
YES
FINAL PLAN DEVELOPMENT
6. ADOPTION OF FINAL PLAN
7. FINAL DESIGN ANALYSIS
8. PERSONNEL RESPONSIBILITIES
9. RECORDS & REPORTING PROGRAM
10. BUDGET OR FUNDING REVIEW AND ALLOCATION.
NO
REGULATORY AGENCY (FINAL PLANS, ETC.)
YES
CONTINUING STUDIES
1. OPERATING NEEDS
2. INSPECTION AND REVIEW INDICATORS.
3. MONITORING INDICATORS
4. COST EFFECTIVENESS
5. UPDATED RECORDS AND REPORTING PROGRAM.

Figure 13-4

negative approach is avoided. It is very easy to point out existing and potential problems without relating them to the whole picture. A positive and practical approach is required that may require elements of compromise.

To a large degree, the success or failure of an existing or proposed refuse embankment is dependent upon how ground water is controlled. This control applies to seepage conditions through both the foundation and the embankment. The introduction of water into and earth or coal refuse embankment is probably the greatest single factor influencing the stability of the embankment. Therefore, investigation of permeability characteristics of embankment and foundation materials is essential. In addition, percolation of water through coal refuse materials often results in degraded water, usually highly acid, which can pollute waters downstream from the site. If the dump is burning, seepage water may be thermally degraded, or even in a gaseous state. Temperature can affect both seepage rates and the quality of water. Hydrogeologic investigation should include analysis of foundation materials, both solids and bedrock, and analysis of embankment materials. Both hydraulic characteristics and water quality considerations should be included in these analyses.

13.2.2.1 Hydrologic Investigations--Hydrology deals with the quantities, distribution and circulation of precipitation and water both in the atmosphere and on the land. Hydrology is the science used to relate the phenomenon of precipitation to surface runoff. This runoff must be either impounded or routed past any restriction in its path or serious erosion or failure could result. The importance of performing an adequate hydrologic investigation to evaluate the impact of precipitation on an impoundment and the possible hazard that could result from an adverse combination of hydrological factors which could produce unusually severe flood conditions, therefore, cannot be overemphasized.

A flood, as defined herein, is any relatively high flow that overtops the natural or artificial banks in any reach of stream and consequently constitutes a hazard to structures which lie along or partially block the natural drainage path. Where the stream channel is blocked by a coal refuse disposal structure, high precipitation and possible overtopping of the structure, resulting in embankment failure with the consequent release of impounded water, constitutes a severe hazard. A common mode of catastrophic failure for many types of earthfill structures is initial overtopping by stored water resulting from the lack of adequate flood bypass facilities, such as spillways or control structures. Once overtopped, an earthfill structure may fail in minutes.

Flood flows are normally the result of intensive precipitation. However, the amount of water that directly becomes runoff and the speed at which this runoff accumulates and forms a flood peak can vary substantially because of different terrain conditions. Once the precipitation reaches the ground, the runoff may be delayed or modified by such factors as freezing and thawing, vegetal cover, antecedent precipitation and soil moisture, land use, infiltration which relates to the type of soil and basin geometry which relates to the size, shape and slope of the drainage area. Generally, these factors are relatively similar for specific regions. However, there can be substantial differences within a region and care should be utilized to recognize these differences.

The climatic conditions which are responsible for the rainfall and snow can also vary significantly within a region. Localized storms, as well as large regional storms, would, in fact, be expected to vary, with nonuniform precipitation intensities and durations occurring simultaneously throughout the entire area. All these factors, those relating to precipitation and those relating to ground conditions, must be considered if a realistic and safe design of a coal refuse deposit which can safely pass flood flows is to be accomplished. Moreover, all of these factors are an established part of ordinary earth dam design procedures.

In addition to the previous factors, small rural watersheds, due to overland flow, have different runoff characteristics than larger ones. Overland flow is that water which travels over the ground surface to a watercourse and is the dominating factor for small watersheds. Because of the overland flow factors, small watersheds are more sensitive to high intensity rainfall of short durations and to land use. Small watershed are defined as a watershed of 10 square miles or less. The effects of channel flow and basin storage suppress these sensitivities on larger watersheds. The significance of all this is that a short, intense storm would cause a high, flashy, flood peak on a small watershed and a lower, though longer lasting peak on a larger one. This implies that basic hydrologic data collected by the U.S. Geological Survey and other agencies on larger streams throughout the country over a long period of time cannot always be readily transposed from large, nearby watersheds to smaller ones, without major modifications being applied to the data. The same applies for design techniques developed for impoundments on large watersheds.

One of the more critical phases of hydrologic planning relates to the determination of a peak design flood. Designing for the flood with a recurrence interval of once in ten years or once in one hundred years, or any other flow below that which is considered the maximum possible flood involves a calculated risk because there is always a chance that a maximum possible storm may occur. Localized thunderstorms represent a particular threat to a small watershed. The chance does exist of an extremely intense storm occurring over a very small area, one square mile or less, in an area such as the Appalachian region and such events do occur each year. However, the magnitude of the localized runoff from such a storm would represent a relatively rare event for a specific watershed as a whole and could have a theoretical recurrence interval of a 500 year or even a 1,000 year flood if applied to an entire large watershed.

The selection of a design frequency must rest on economic analysis policy decisions and local practice, after a careful evaluation of the consequences of a failure are ascertained. As a rule, some risk not associated with the loss of human life must be accepted. The degree of risk depends on flood characteristics and potentialities in the basic and on the extent of development downstream of the proposed or existing deposit.

Flow frequency analysis is used by engineers as an aid in the evaluation or design of water-use or control projects. Such an analysis provides the final solution for a flow problem in some cases, but in most cases, the analysis is only one of the steps in an engineering study in which the project evaluation or design must advance beyond the scope of flow frequency analysis. In the latter case, determination of the probable maximum flood is often required by regulatory agencies.

A flow frequency analysis consists of a study of past records of flow, followed by a statistical estimate of frequencies of future flows. If such records are available and cover a period of 20 years or more, the flood flows shown by the records may be analyzed to provide flood frequency values. Outstanding flood events can be analyzed to provide runoff factors for use in determining the probable maximum flood.

Flow records which cover only a few years may not include any flood of great magnitude and should not be used without comparing the results with data from nearby watersheds which have similar runoff characteristics. However, analysis of the results may give some or all of the runoff factors needed to compute the probable maximum flood.

Statistical analysis of flow records does not provide reliable estimates of probable maximum flood flows. The determination of the probable maximum flood should be based on a study of storm potential, and runoff distribution as related to the physical characteristics of the watershed. Generalized charts for estimating probable maximum precipitation east of the 105° meridian are published in Technical Report No. 40, U.S. Weather Bureau, Department of Commerce.

Step by step procedures for computing the probable maximum flood are presented in Design of Small Dams, Bureau of Reclamation, Department of the Interior, 1965, p. 19-61. These procedures cannot usually be applied to small watersheds since rainfall and runoff data are often lacking and bacause of the widely varies physical nature of small basins.

When basic data is insufficient or lacking, empirical, or semiempirical methods are used for estimating peak runoff from small watersheds. Many of these methods are inadequate for evaluating the hydrologic factors involved and the results obtained are often unreliable. The better methods for estimating peaks, when historic and other hydrologic data are unavailable, are those which correlate such factors as rainfall intensities, land use, watershed dimensions, slope and frequency of occurrence which have been developed and tested for a specific region. Several of these methods and a brief description are listed below:

1. The U.S. Bureau of Public Roads Method--This method makes use of a topographic index and a precipitation index. These indices vary from place to place, resulting in a series of relationships, expressed as curves, for different parts of the United States.

2. The Cook Method--U.S. Soil Conservation Service--This method uses an empirical relationship between drainage area and peak flow with modifications for climate, relief, infiltration, vegetal cover and surface storage. Charts are presented for easy application.

3. The Chow Method--relates peak flow to rainfall excess and has charts for runoff, climatic and other factors. Developed primarily for Midwestern areas.

4. Various State Highway Methods--Many states have developed their own data and methods. Some of these provide fairly reliable results.

Procedures and references for using these methods are presented by: Chow, V. T., *Handbook of Applied Hydrology*, McGraw-Hill Book Company, New York, 1964, pages 25-16 to 25-25.

Maximum flood peaks do not always represent the most critical aspect of flood flows. Since the majority of coal refuse deposits are constructed on small watersheds and are sensitive to high intensity rainfall of short duration, the incoming peak flows resulting from such a storm will have a high peak flow but the volume of water contained by the flood will not be exceptionally large because of the short duration. Another storm with smaller rainfall intensities but with a much longer duration can produce a larger volume of water. In situations involving coal refuse impoundments, various storm conditions should be considered.

13.2.2.1.1 Seepage and Pore Pressure The destructive power of water is well recorded in the annals of history. Water moving through soil pores and rock fractures is capable of exerting forces that can cause massive landslides or destroy major engineering works. Seepage theory has been developed in great detail in many textbooks; however, discussion relating to practical application of the theory is available in only a few. As with most analytical tools available to the engineer, mathematical theory is the basis of seepage analysis. It is, therefore, incumbent upon the engineer to develop these parameters used in the analysis in a way that is consistent with the theory and accurately reflects the actual conditions.

In performing a seepage analysis, even though the analysis itself may have a high degree of reliability, the result may be greatly in error if the assigned permeability is in error by a factor of even 100. Since permeability may change during the life of the structure, and laboratory test results can easily differ from field results by a factor of 1,000, most experienced engineers regard seepage theory as a means of predicting the general order of magnitude of problems and to indicate potential problem areas that require special design consideration. In this light, it is easily understandable that there exists no substitute for field observations and periodic surveillance of earth structures such as coal refuse dumps and impoundments.

The need for control of pore water pressure and seepage in earth structures is well recognized. The forces of gravity are constantly being exerted downward on all soil and rock. These same forces act on water in soil voids and thus seepage forces develop within the soil mass. Under the proper combination of soil and pore water conditions, the potential for mass instability can become great.

Pore water pressure and seepage forces are quite different; in fact, they are virtually opposite. Pore water pressure has to do with the motion of the embankment material, while seepage forces are caused by the motion of the water through this material.

When an embankment is placed, the lower layers, both of the foundation and the embankment material, compress under the load of the material above. The individual particles do not themselves compress, rather they rearrange themselves under the force of the weight above. As a result, compression necessarily leads to a reduction in the relative amount of empty space (the volume of the so-called "pores") in the soil.

If the pores contain any water, this reduction in pore volume may lead to a saturated condition where the pores are completely filled. Even if the material in the embankment was not saturated when it was placed, it may readily become so as it compresses (this compression is called "consolidation"). Reaching saturation is a critical condition, due to the incompressibility of water. Once saturation is reached, no more consolidation can occur until some of the water has been squeezed out of the weighted, or loaded, material. In the interim any added load will literally "float" upon the water in the soil, creating only water pressure rather than consolidation.

This pressure, i.e., the water pressure over and above that caused by the weight of the water itself, is called excess pore water pressure.

Excess pore water pressure is serious for several reasons. First, as long as it exists, say in the bottom layer of an embankment, the material above that layer is not exerting its full weight upon the foundation. But the frictional resistance to motion over the foundation is a direct function of how much weight is exerted. If most of the weight is being carried by the water and is thus unavailable for frictional resistance, the entire embankment might slide forward propelled by the water impounded behind it (indeed, some witnesses have spoken of dams which failed in this way as "opening like a gate on hinges").

Even when no water is impounded, as when an impoundment is under construction or material is simply being piled up, excess pore water pressure may cause failure along an including surface because the weight of the material above is greater than the frictional resistance along the surface. Such a surface, or "failure plane", may even form within a homogeneous mass of material, leading to sudden and catastrophic failure.

It must not be thought that because excess pore water pressure is a transient phenomenon it is thereby short-lived. For a fine-grained material such as clay, silt or fine sized coal, it might take a dozen years for the excess pore pressure in a consolidating zone to fall by one half. Total consolidation in clay can often take a century, at least in theory. It is the great slowness with which excess pore pressure abates in fine soil that makes necessary the very flat slopes found on earth dams built upon such material. These dams must be designed to float on the saturated soil, because it is not economical to wait for even partial consolidation. However, in the same terms, the coal refuse disposal area which is to be developed over a period of years may be able to take advantage of the partial consolidation which will occur and use steeper slopes than those found in earth dams, thus saving land area. Indeed, this partial consolidation effect apparently accounts for the fact that many existing mine refuse embankments stand at slopes which are deemed impossible under conventional earth dam design theory.

The second serious consequence of excess pore water pressure is that it causes seepage and seepage forces. In order for the excess water to squeeze out of a consolidating mass it must flow through the pores of the material, which causes a frictional force in the direction of flow. Such forces are called seepage forces.

Seepage forces may be caused by conditions other than excess pore water pressure due to consolidation; in fact, they will occur wherever water flows or "seeps" through a porous medium. Such forces are always present, for example, in the lower layers and foundation of an embankment, which impounds water, or in the hillside beneath a perched or hilltop reservoir. Moreover, seepage forces may act in any direction, depending upon where the water must flow in order to reach lower pressure. Such directions may be difficult to predict because the ease of flow, or "permeability" may vary greatly from one direction to another at any given spot. In general, however, the seepage forces in an embankment which is consolidating will be more or less horizontal and outward from the center. These forces can be large and can contribute considerably to the gliding-type failures described above.

When impounded water seeps under an embankment, the seepage forces at the "toe", or downstream edge, will often be vertical as the water escapes from the ground. This condition, which can be very serious, may sometimes be recognized by such things as active seeps, boils or quicksand near the toe or by a heavy stream flow in dry weather. If such conditions are observed, action should be taken at once to either lower the level of the impounded water or alleviate the excess pore water pressure at the toe by means of drains, because the toe of an embankment is particularly critical to its stability.

If a condition of excess pore water pressure is anticipated or is throught to exist, this can be detected and monitored by a device called a piezometer. If piezometers are installed when a disposal site is developed and carefully monitored, they may be used to plan the placement of material to achieve relatively steep slopes with safety.

Since the soil mass of slopes may contain moisture but be free of excess pore water pressure and quite stable because seepage forces have not developed, a knowledge of internal water force is critical to safe and economic design. Therefore it follows that adequate stability anaylsis is contingent upon a thorough understanding of the internal water conditions of dumps and embankments.

No engineering property of soil materials is more variable than the coefficient of permeability. The three areas that influence permeability are: 1) factors associated with the properties of the water or other permeant, 2) factors associated with the physical properties of the soil, and 3) chemical effects of the soil-water system. The following chart (Figure 13-5) by Cedergren is for inert soil particles; coal refuse has permeability characteristics which also vary over at least this wide a range.

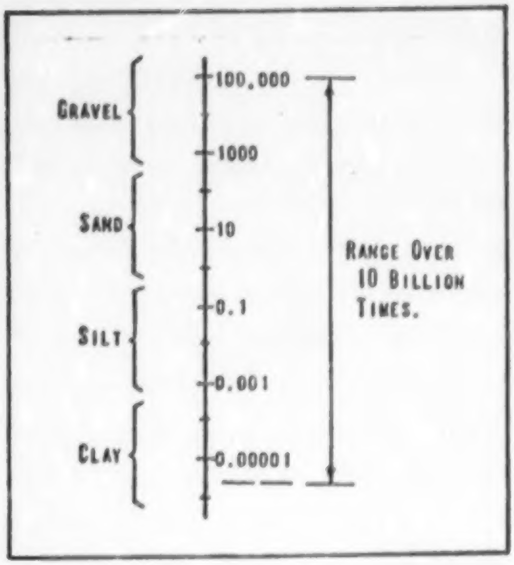


Figure 13-5
Coefficient of Permeability (Ft/Day)

Although the quantity of seepage exiting an earthen structure is important for dams, it has little consequence in analysis of dumps and impoundments providing the discharged water is controlled, i.e., internal soil erosion (piping) is nonexistent and surface erosion is tolerable. The crucial elements in a satisfactory stability analysis are engineering properties of the material involved, seepage forces, internal static hydrostatic pressure and the upper boundary or line of saturation. This saturation boundary is often referred to as the phreatic surface. It is important to note at this point that a theoretical seepage analysis may be a futile academic exercise if the embankment construction technique is not known with reasonable accuracy, if the operation of the impoundment is at variance with the analysis, or even if the refuse material changes as the coal seam characteristics change.

The flow of water through a porous medium (soil) may be represented analytically by the LaPlace Transform. This transform governs the two-dimensional flow of an incompressible liquid (water) through an incompressible porous material (soil particles). Graphically the LaPlace equation may be represented by a set of curves that, taken as a group, are known as a flow net. The flow net has been generally accepted as a method of studying pore pressure and seepage flow, and is widely used for evaluation of seepage conditions in embankment type structures. For practical solutions to engineering problems, mathematical solutions have proven to be unmanageable even with the use of sophisticated computer programs, but fortunately a useful flow net can almost always be prepared by a practiced soils engineer. The development of a useful flow net, however, demands a knowledge of materials behavior as well as of the limitations of the boundary conditions inherent in the mathematical analysis.

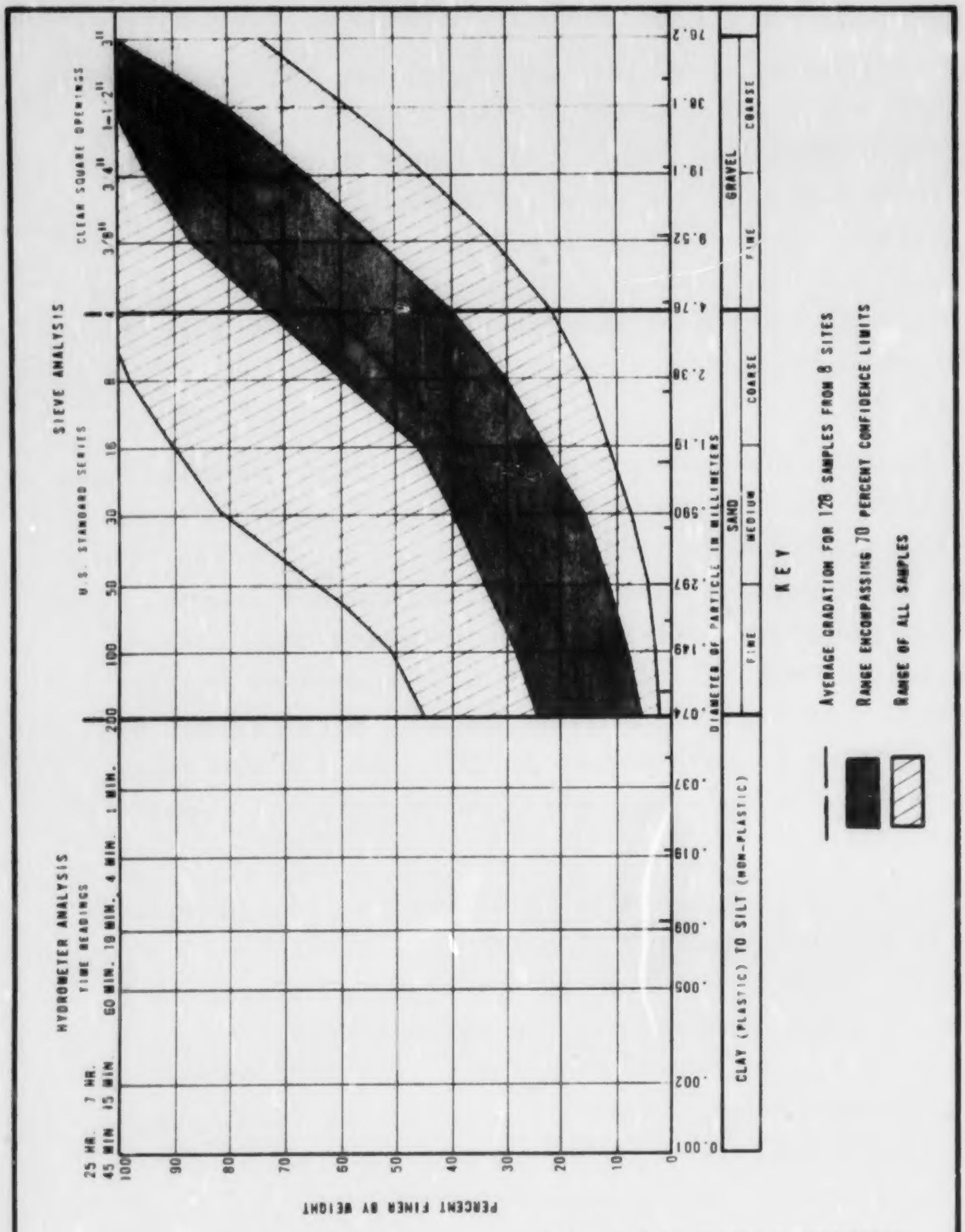
13.2.2.2 Stability Analysis In the last 20 years, both understanding of soil shear strength by the engineering profession, and methods of laboratory testing and soil sampling have been vastly improved. In addition, improved methods of computations for stability analyses have been developed. As a result of this progress, and also because of the great need which exists for an analytical means of estimating the margin of safety of earth dam embankments against shear failure, stability analyses have become firmly established analytical procedures. It must be kept in mind, however, that nearly all computation procedures are based on assumptions which are often, of necessity, gross simplifications of conditions which may actually exist. Therefore, stability analyses should be considered primarily of value as a tool to evaluate an embankment's relative stability rather than a procedure which produces absolute, inflexible numerical results. There is no substitute for practical experience and the judgment which it brings. Great caution is required in the interpretation of the results obtained by stability analysis which have been tested primarily upon well-compacted, quickly erected embankment dams. When one uses the absolute numerical value of the safety factor to justify the acceptability of a given design, reliance is being placed on several assumptions, the validity and limitations of which are often not well understood. But it is easy to show that small changes in assumed shear strength parameters or pore water pressure cause appreciable differences in the calculated results. Therefore, because the specific gravity of the sludge derived from the separation process is very low and the average shear strength parameter high, a doubly difficult problem exists when sludge forms the foundation for a coarse refuse deposit.

13.2.2.3 Physical Properties of Coarse Coal Refuse

The physical properties results presented herein were compiled from the test results produced by W. A. Wahler and Associates in conjunction with research work performed for the U.S. Bureau of Mines and the Mining Enforcement and Safety Administration, and investigatory and analytical work for coal mining companies. Several other references were reviewed and, where available, appropriate data have been included. Two references in particular, "Tentative Design Guide for Mine Waste Embankments in Canada", prepared for the Mines Branch Mining Research Center, and "Spoil Heaps and Lagoons", a technical handbook prepared by the National Coal Board of England, contained specific test results which have been included for comparative purposes. Other than the two cited references, and the results from W. A. Wahler and Associates' detailed work at some ten sites located in West Virginia, it must be concluded that detailed, publicly available information on the index and engineering properties of coarse coal refuse is limited. The data which are presented, however, represent a cross section of industry practices and are probably indicative of results that would have been developed had there been a greater amount of data available for review.

As mentioned previously, the effect of consolidation, the influence of degradation (caused by natural weathering) and accelerated weathering associated with burning refuse dumps are important areas of needed future research. The data on the physical properties of coarse coal refuse as presented herein indicates that a breakdown or degradation of the coarse coal refuse does occur. However, the data are inconclusive with regard to the specific influence that such degradation may have on the material properties characteristics.

13.2.2.3.1 Grain Size Distribution This gradation results for 128 samples of coarse coal refuse are presented on Figure 13-6 in the form of a range of all samples tested, a range encompassing 70 percent of all data, and the arithmetic average. These data represent gradation results from burning as well as nonburning refuse dumps which were constructed by aerial tram or random truck dumping methods. While these data have a rather broad range, elimination of the upper and lower 15 percentiles reveals a reasonably narrow range for the remaining 70 percent. The heights of the refuse dumps from which the data were obtained range from tens to several hundreds of feet. Similar data on grain-size distribution from the National Coal Board of England and the Canadian Mining



Source: W.A. Wahler & Associates

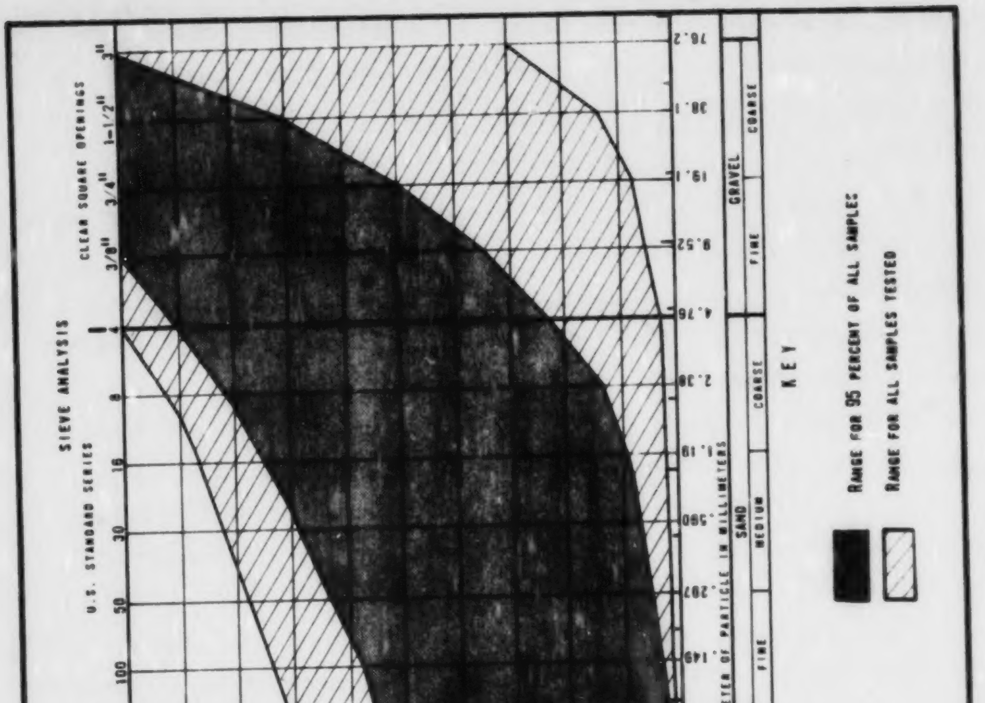
Figure 13-6

GRADATION SUMMARY
COARSE COAL REFUSE

Research Center are presented on Figures 13-7 and 13-8, respectively. The data shown on Figures 13-6 through 13-8 indicate the same general band of gradation results. Sufficient data were not available from these sources to determine the middle 70 percent distribution of test results.

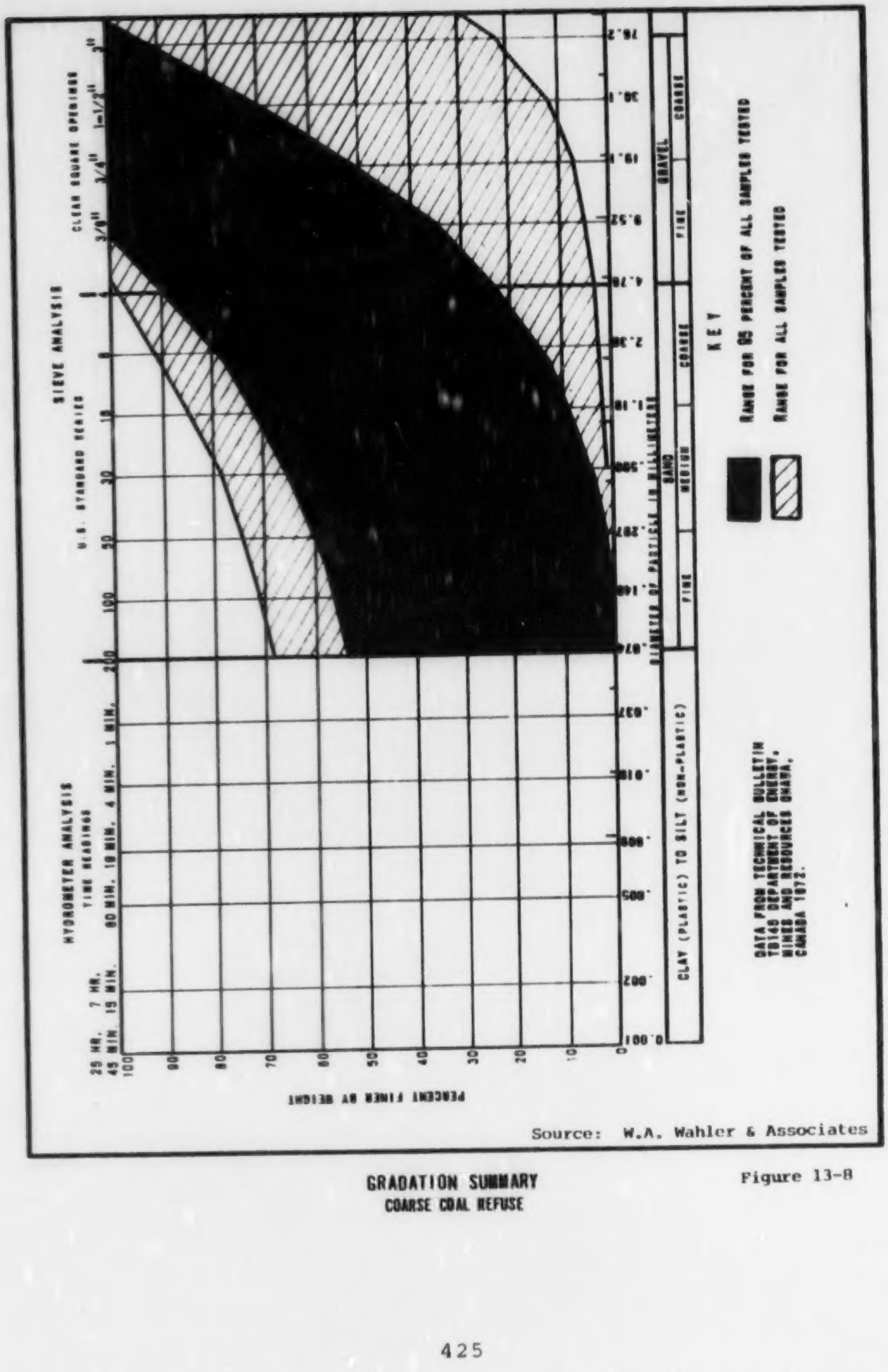
The effects of particle breakdown due to weathering and handling are clearly shown on Figure 13-9, which presents the average gradation results of "fresh" coal refuse from three sites, as well as the average gradation for the 128 samples referenced on Figure 13-6. These samples were obtained directly from the surface of the dumps within one day after deposition. When comparing the average gradation results of all samples with those of the fresh material, it is observed that the material when originally deposited on the dumps was classified as well-graded gravel with more than 60 percent of the material coarser than the #4 sieve and less than 10 percent finer than the #200 sieve. The gradation results for the average of all samples tested, however, indicate that less than 40 percent of the material is coarser than the #4 sieve and approximately 15 percent of the material is finer than the #200 sieve. The approximate parallel nature of the two average gradations shown on Figure 13-9 below the #4 sieve indicates that the majority of the breakdown is occurring on the plus #4 particles sizes.

Only 18 gradation results were available for completely degraded coarse refuse, commonly referred to as red dog. Although these results are not presented herein, the average gradation for the 18 samples was almost identical to that of the average for the 128 samples referenced on Figure 13-6. These results could be misleading, however, because sampling and testing of this type of material is



Source: W.A. Wahler & Associates

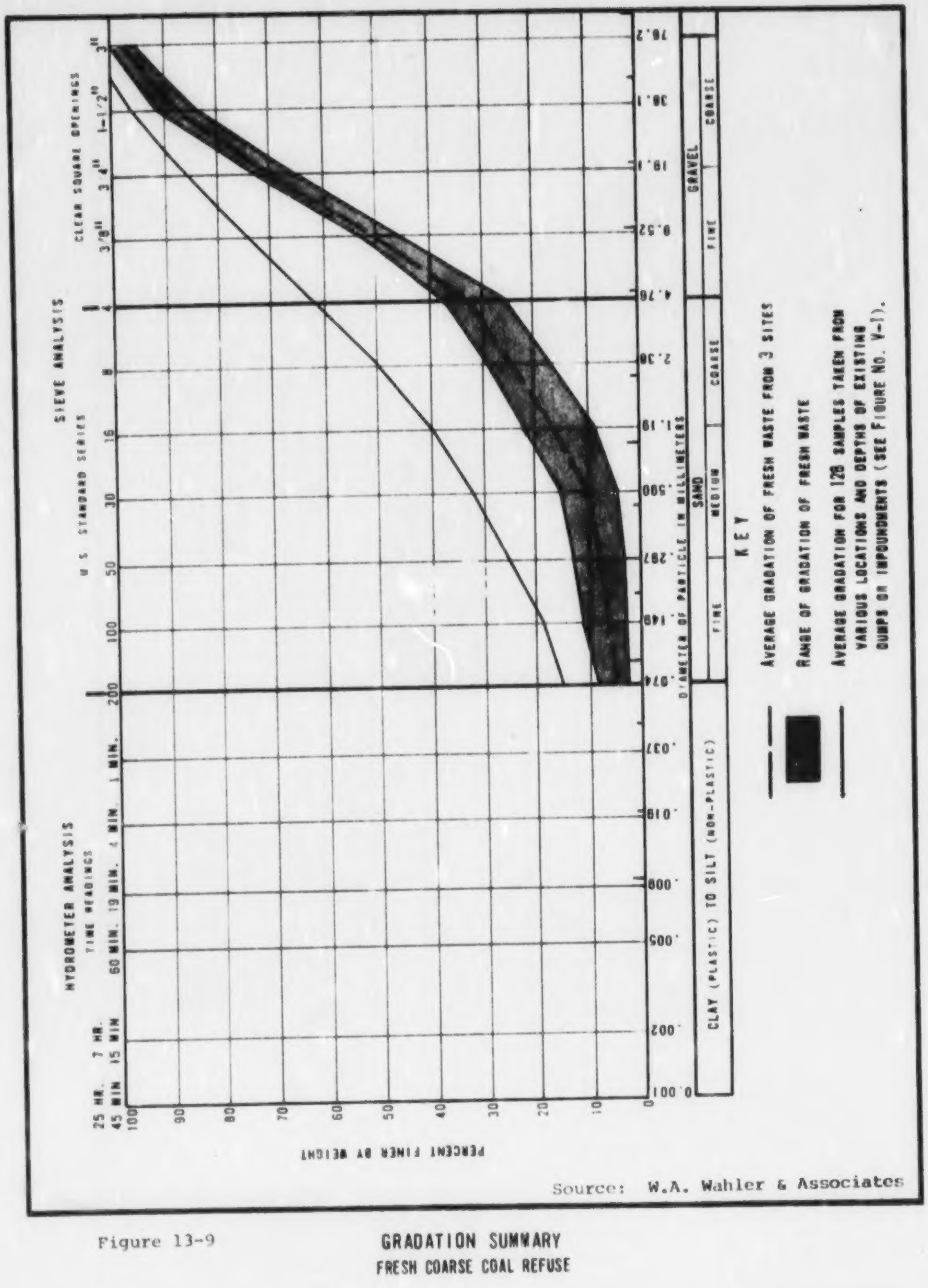
Figure 13-7 **GRADATION SUMMARY**
COARSE COAL REFUSE



Source: W.A. Wahler & Associates

GRADATION SUMMARY
COARSE COAL REFUSE

Figure 13-8



Source: W.A. Wahler & Associates

Figure 13-9 GRADATION SUMMARY
FRESH COARSE COAL REFUSE

extremely difficult. When the burning of a refuse dump goes unchecked, the coarse refuse sometimes fuses together into blocky masses with maximum dimensions as great as one to four meters; other times, the burning produces large lenses of fine, powdery material.

13.2.2.3.2 Atterberg Limits The majority of the coarse refuse material is nonplastic. A total of 17 samples out of some 150 samples tested in the laboratory exhibited some plasticity and results are presented in Figure 13-10. The average results indicate a liquid limit of 30 percent and a plasticity index of less than 10.

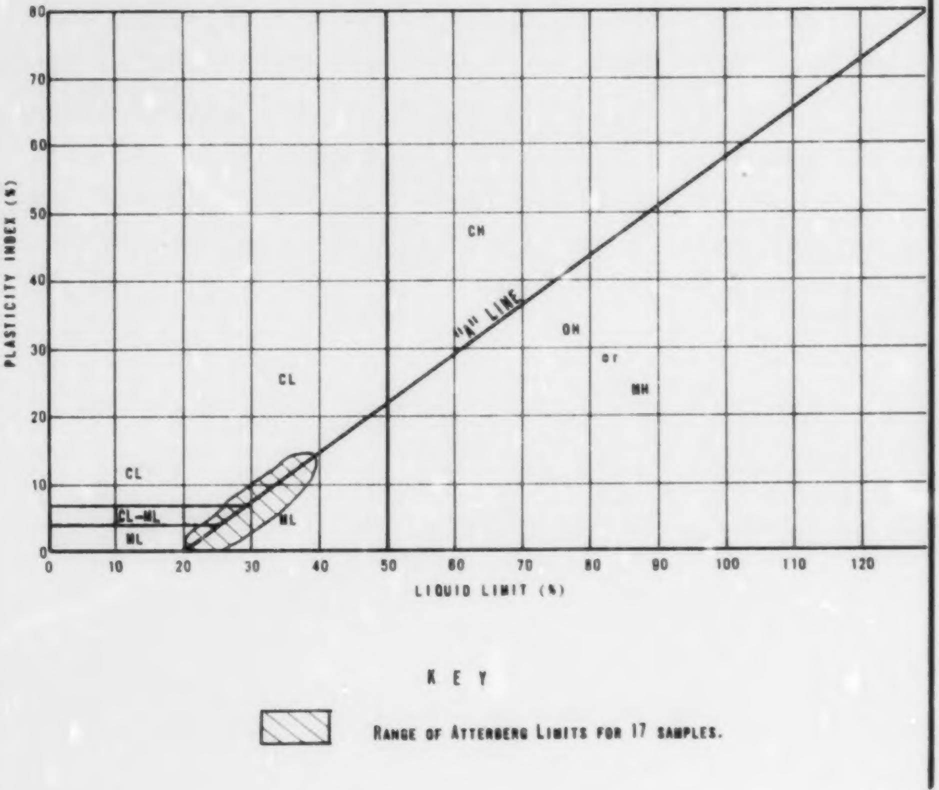
13.2.2.3.3 Specific Gravity Specific gravity values for the coarse coal refuse vary from about 1.6 to greater than 2.4, depending upon the composition of the materials. The specific gravity results for 37 coarse refuse samples are presented in Table 13-1, below.

Table 13-1

Specific Gravity Results for Coarse Coal Refuse

Number of Samples	Range of Specific Gravity
3	1.60 - 1.80
9	1.81 - 2.00
13	2.01 - 2.20
4	2.21 - 2.40
8	2.40
Average Specific Gravity = 2.14	

13.2.2.3.4 Natural Water Content and Dry Density The natural water content and dry density of coarse coal refuse depends directly on the method of disposal used and whether or not the dump is burning. Results for the in-place water content and dry density obtained from eight sites in West Virginia are summarized in Figures 13-11 and



Source: W.A. Wahler & Associates

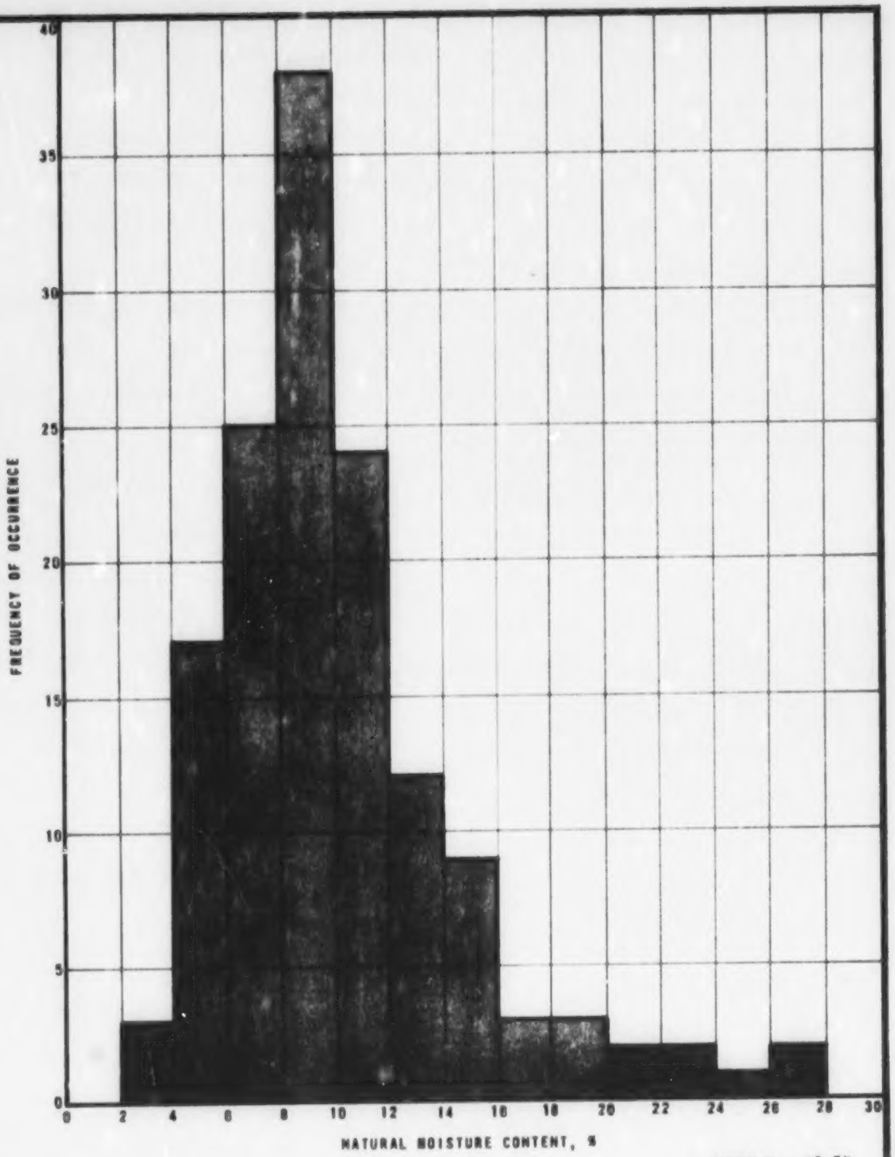
Figure 13-10 ATTERBERG LIMITS
COARSE COAL REFUSE

13-12, respectively. These data were obtained from both field density testing and measurements obtained in the laboratory. The water content results shown in Figure 13-11 indicate a range from 2 percent to 28 percent, with approximately 90 percent of all data falling between 4 percent and 16 percent. The arithmetic average of the natural moisture content based on dry weight for the 141 samples tested was 10.4 percent. In-place dry density results, shown on Figure 13-12, indicate a wide range from 60 to 116 lb/cu ft (pcf), with about 84 percent of the results higher than 80 pcf. The arithmetic average of the 137 samples was 90.4 pcf.

As mentioned previously, it is very difficult to obtain undisturbed samples of burning coal refuse. The excessively high temperatures associated with this problem (above 500° F.) makes drilling and sampling of these materials hazardous. Obviously at these elevated temperatures, all free water is driven off. The natural moisture content and dry density data presented on Figures 13-11 and 13-12 contain the results of only a few samples obtained for burning coal refuse. More research regarding the physical composition and engineering properties of burning coal refuse is needed.

13.2.2.3.5 Compaction Characteristic. A total of 38 compaction tests were performed on coarse coal refuse in accordance with ASTM D-1557-70, modified to 20,000 ft-lb/cu ft compactive energy. The results are presented in Table 13-2.

The compaction test data presented in Table 13-2 indicate a broad range in maximum laboratory densities from 76.2 to 123.7 pcf. A somewhat progressive increase in maximum laboratory density can be seen when the data are grouped according to ranges of specific gravity. The major

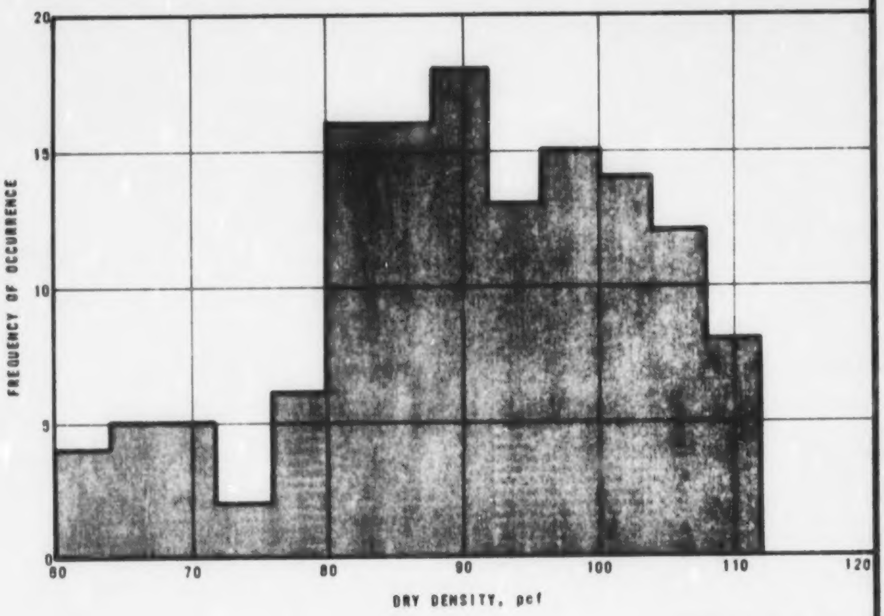


AVERAGE = 10.7%

NOTE: THE NATURAL MOISTURE CONTENT DATA SHOWN HEREON ARE REPRESENTATIVE OF 141 SAMPLES OBTAINED AS EITHER IN-PLACE DRY DENSITY OR UNDISTURBED TUBE SAMPLES FROM 8 SITES IN WEST VIRGINIA.

Source: W.A. Wahler & Associates

Figure 13-11 NATURAL MOISTURE CONTENT
COARSE COAL REFUSE



AVERAGE = 90.4 pcf

NOTE: THE DRY DENSITY DATA SHOWN HEREON ARE REPRESENTATIVE OF 134 SAMPLES OBTAINED AS EITHER IN-PLACE FIELD DENSITY OR UNDISTURBED TUBE SAMPLES FROM 8 SITES IN WEST VIRGINIA.

Source: W.A. Wahler & Associates

IN-PLACE DRY DENSITY
COARSE COAL REFUSE

Figure 13-12

factors influencing the scatter of data are the difference in specific gravity and gradation for the individual samples tested.

Table 13-2

Compaction Characteristics--Coarse Coal Refuse

Number of Tests	Range of Specific Gravity	Laboratory Compacted Maximum Dry Density, pcf			Optimum Moisture Contents, %		
		Low	High	Average	Low	High	Average
3	1.75 - 1.80	76.2	95.5	87.7	7.5	19.5	12.6
8	1.81 - 2.00	89.9	104.4	98.6	7.5	14.0	10.5
13	2.01 - 2.20	90.6	108.5	102.5	6.5	11.5	9.7
14	2.21 - 2.63	92.2	123.7	109.4	7.5	15.0	11.7

13.2.2.3.6 Permeability The coefficient of permeability as used by the soils engineer is the superficial velocity of water as it passes through a soil under a unit gradient. The value of the coefficient of permeability reflects the ease with which water will flow through a soil and must be known in order to calculate the quantity of flow. The range of permeability reflects the ease with which water will flow. The range of permeability for soils is extremely great, varying from greater than 1 cm/sec (1,000,000 feet/year) for clean gravels to 10^{-8} cm/sec (0.01 feet/year) or less for clays.

Approximate values of permeability can be obtained by field testing procedures. The reliability of the values obtained depends on the homogeneity of the stratum tested and on certain restrictions of the mathematical formulas used. If reasonable care is exercised in adhering to the recommended procedures (see Hovrslev, 1949, or United States Bureau of Reclamation Test Method E-18), useful results can be obtained.

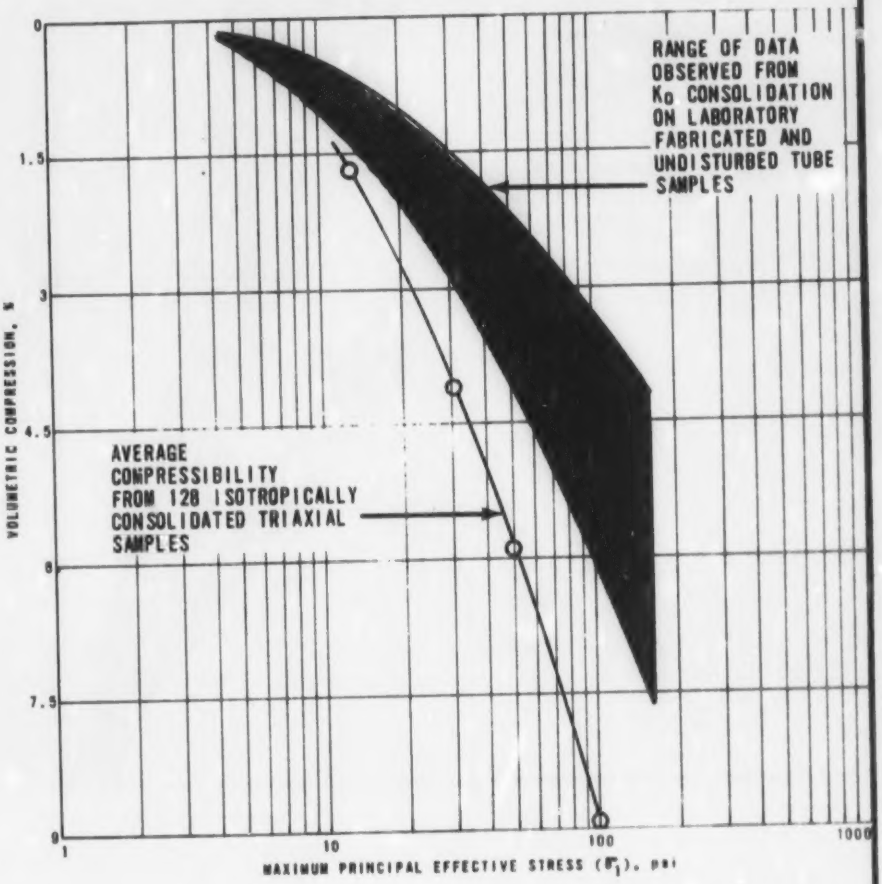
Two methods of determining the coefficient of permeability that are used most often in the field are the infiltration or pumping-in tests and the pumping-out test. In the first method, water is introduced into a drill hole or test pit of known dimensions, and the rate of seepage observed under a fixed or variable head. The second, and less used method, involves the drawing out of water at a constant rate from a drill hold and observing the rate of drawdown on the water table in observation wells placed in a geometric pattern, usually radially at various distances from the point of water withdrawal. Interpretation of test data must be made on the basis of simplified formulas or flow net analyses with application of proper judgment regarding geological factors such as channeling, layering and the anisotropic characteristics of the deposits.

The permeability characteristics of the coarse coal refuse materials were evaluated by reviewing both field and laboratory test data. Values of the coefficient of permeability range between 10^{-2} and 10^{-6} cm/sec, with a typical value of 10^{-4} cm/sec. Similar permeability data are presented to the National Coal Board of England reference for coarse coal refuse with values ranging from 10^{-2} to 5×10^{-6} cm/sec. The ratio of horizontal to vertical permeability, which is needed to correctly construct a flow net for a given impoundment, does not seem to vary significantly for the sites investigated. Unlike compacted material, which usually exhibits a ratio of k_h to k_v on the order of 10 to 50, the permeability results of the corase refuse indicate a ratio of less than 10, with a majority of the results less than 2. The low ratio of k_h to k_v is undoubtedly due to the lack of compaction and the generally loose nature of most of the impoundments studied.

13.2.2.3.7 Compressibility The compressibility characteristics of the coarse refuse are difficult to investigate in the laboratory because of the coarse nature of the materials. Data from saturated, isotropically consolidated triaxial tests, as well as one saturated anisotropically consoldidated triaxial sample, with average initial densities varying from 85 to 95 pcf, were evaluated and the results are presented in Figures 13-13 in the form of axial strain versus maximum effective principal stress for the sample consolidated under K_o conditions (no lateral deformation) and volumetric strain versus maximum effective principal stress for the isotropically consolidated samples.

A range of volumetric compression of 3 to 6 percent was observed for the anisotropically consolidated samples as compared with 9 percent for the isotropically consolidated samples at 100 psi maximum principal effective stress. This stress corresponds to an embankment height of about 150 feet. Because of the relatively high permeability value of the coarse material, the time delay associated with the consolidation process is extremely short. In other words, the straining within a saturated embankment due to a load application would occur very rapidly. Additionally, the magnitude of the volumetric compression is considered to be high when compared to an average value of less than 3 percent volumetric strain at 100 psi for a well-compacted material with similar gradation characteristics to that of the coarse coal refuse.

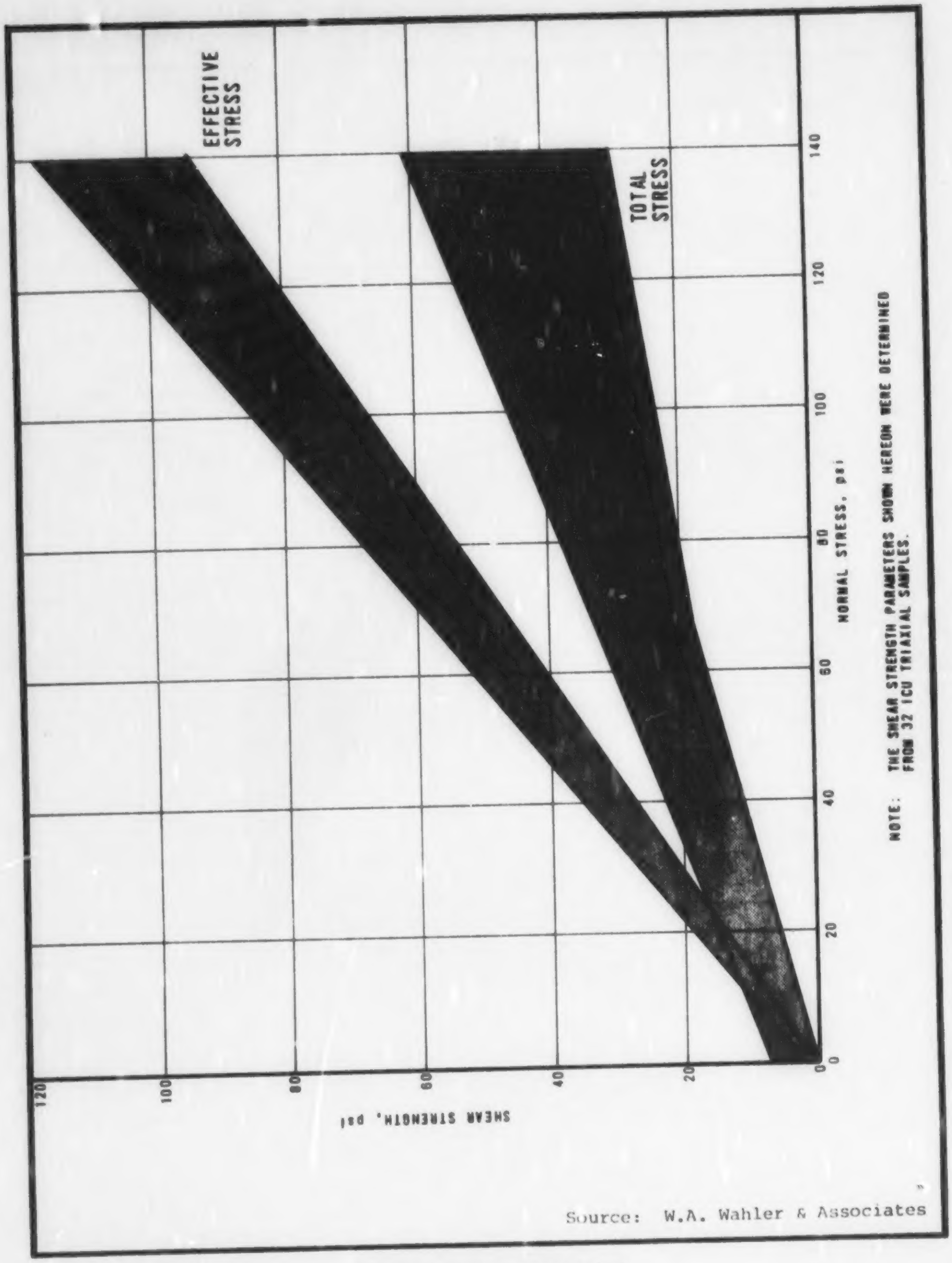
13.2.2.3.8 Shear Strength Shear strength parameters of the coarse refuse material were determined from laboratory triaxial tests performed on 51 samples, and are presented in Figure 13-14 in the form of shear strength



Source: W.A. Wahler & Associates

COMPRESSIBILITY CHARACTERISTICS
COARSE COAL REFUSE

Figure 13-13



Source: W.A. Wahler & Associates

Figure 13-14

SHEAR STRENGTH PARAMETERS
COARSE COAL REFUSE

versus normal stress for both effective and total stress. These samples consisted of either laboratory fabricated or undisturbed tube samples and were tested under ICU test conditions. The shear strength parameters for the coarse refuse materials, based on effective stresses, vary from 34° to 41°, with essentially zero cohesion intercept. It is interesting to note that the dry density of the triaxial samples varied considerably, and yet the effective stress friction angle was found to vary less than 7°. The influence of the scatter in density is more reflected in the shear strength paramteres based on total stresses, wherein the friction angle varied from a value less than 15° to approximately 20° with 7 psi cohesion intercept.

The relatively high values of shear strength of the coarse refuse materials indicate one very important point. Since the material is inherently quite strong when compared to other construction materials, if proper construction techniques are utilized, a dam or dump made with these materials, utilizing current earth dam design standards, can provide a safe, adequate structure.

13.2.2.4 Physical Properties of Fine Coal Refuse

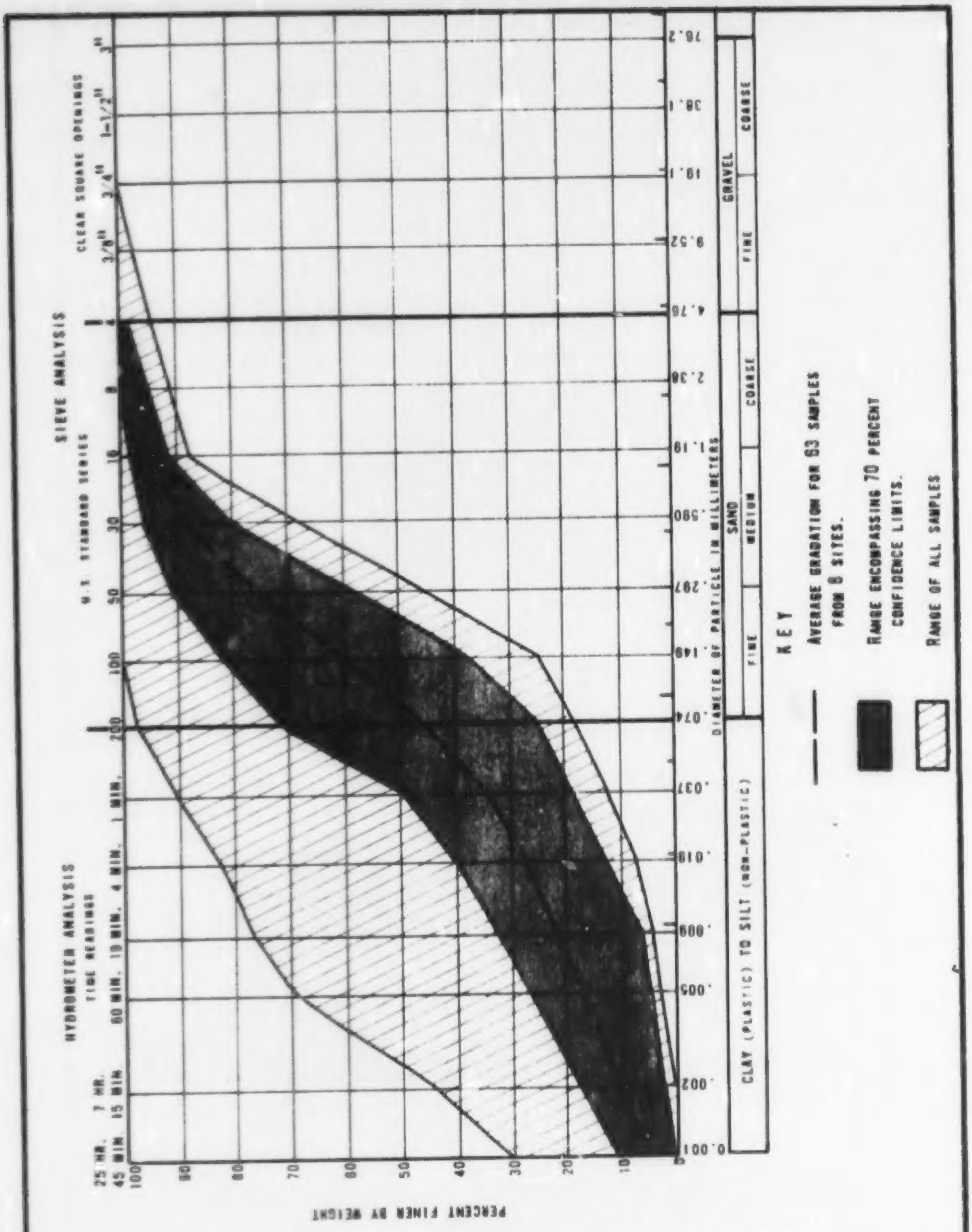
The physical properties of the fine coal refuse materials similar to those for the coarse materials discussed in 13.2.2.3 were also evaluated for the eight sites in West Virginia. Unlike the coarse materials, which are conveyed to the disposal area by aerial tram or dump truck methods, the fine materials are conveyed to the disposal area in a slurry. The physical properties of these materials, particularly in grain-size distribution and resulting in-place dry density, are significantly influenced by the location of the discharge line and the distance of flow before these materials arrive at the settling pond.

13.2.2.4.1 Grain-size distribution--The gradation results for 63 samples of fine coal refuse collected from eight sites in West Virginia are shown on Figure 13-15. The results, presented in the form of a range of all samples tested, a range encompassing 70 percent of all data, and the arithmetic average, indicate that the fine coal refuse materials have an average of 45 percent of the material passing the #200 sieve. The range in percent passing the #200 sieve varies from approximately 18 percent to 98 percent, which merely reflects the influence of the point of discharge and the settling characteristics of the fine refuse materials.

13.2.2.4.2 Plasticity characteristics--The minus #40 fraction of the fine refuse materials is nonplastic. Numerous attempts were made to perform Atterberg Limits testing on the fine refuse materials and although a liquid limit ranging between 30 and 50 percent was achieved on some samples, it was not possible to roll threads to 1/8 inch diameter in order to determine the plastic limit and, therefore, the material must be classified as nonplastic.

13.2.2.4.3 Specific gravity--Specific gravity values for the fine coal refuse vary from about 1.3 to 2.2, depending upon the percentage of coal in the material. The specific gravity results for 30 fine refuse samples are presented in Table 13-3.

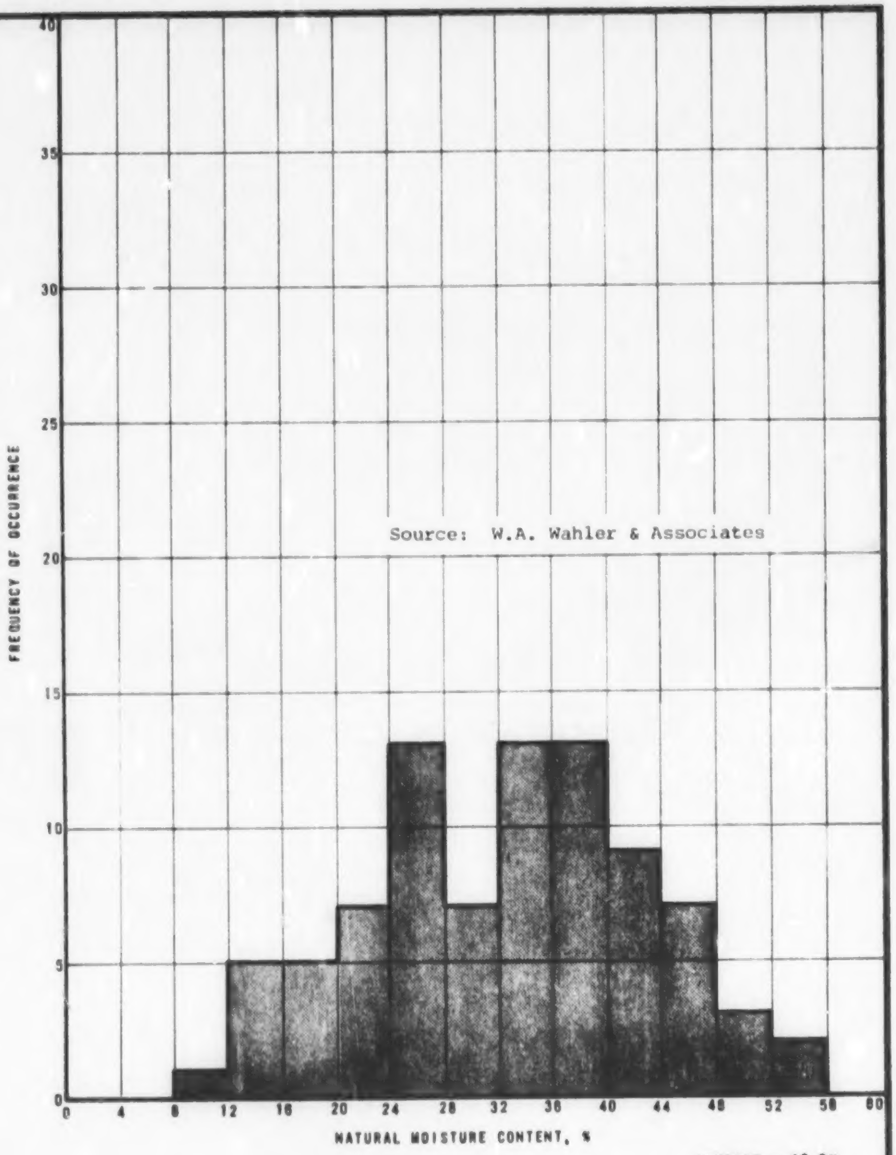
13.2.2.4.4 Natural water content and dry density--The natural water content and dry density of the fine refuse materials were determined from both field density and undisturbed tube samples. Results of the natural water content for 87 samples are shown on Figure 13-16, in the form of observed water content versus frequency of occurrence. A range in natural water content from 8 to 56 percent was observed, with an average value of 30.9 percent.



Source: W.A. Wahler & Associates

GRADATION SUMMARY
FINE COAL REFUSE

Figure 13-15



AVERAGE = 30.9%

NOTE: THE NATURAL MOISTURE CONTENT DATA SHOWN HEREON ARE REPRESENTATIVE OF 87 SAMPLES OBTAINED AS EITHER IN-PLACE DRY DENSITY OR UNDISTURBED TUBE SAMPLES FROM 8 SITES IN WEST VIRGINIA.

Figure 13-16 NATURAL MOISTURE CONTENT

FINE COAL REFUSE

Table 13-3

Specific Gravity Results for Fine Coal Refuse

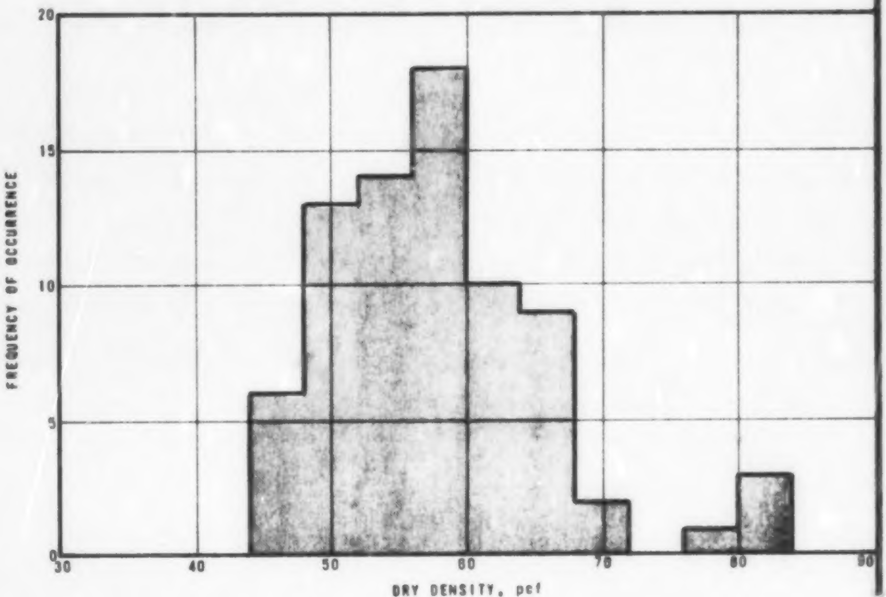
Number of Samples	Range of Specific Gravity
8	1.30 - 1.40
15	1.41 - 1.60
4	1.61 - 1.80
2	1.81 - 2.00
1	2.01 - 2.20

Average Specific Gravity = 1.53

A total of 78 field dry densities were determined for the fine refuse materials and the results are presented in Figure 13-17. The dry density results vary from 44 to 84 pcf with 85 percent of all data ranging between 48 to 68 pcf. The arithmetic average dry density was 55.2 pcf.

Although the density results are exceedingly low for the fine refuse material, when compared to an average dry density of 110 to 120 pcf for typical soil materials, the void ratio of the fine-grain materials indicates a generally close packing of the individual grains. An average void ratio, which is a comparison of the volume of voids to the volume of solids within a given sample, of 0.5 or less is not uncommon.

13.2.2.4.5 Compaction--The moisture density characteristics of the fine refuse materials were determined from a total of 15 samples compacted in accordance with ASTM D-1557-70, modified to 2,000 ft-lb/cu ft compactive energy. The compaction results are presented in Figure 13-18, in the form of maximum compacted laboratory dry density versus moisture content. The data have been grouped according to ranges of specific gravity and the

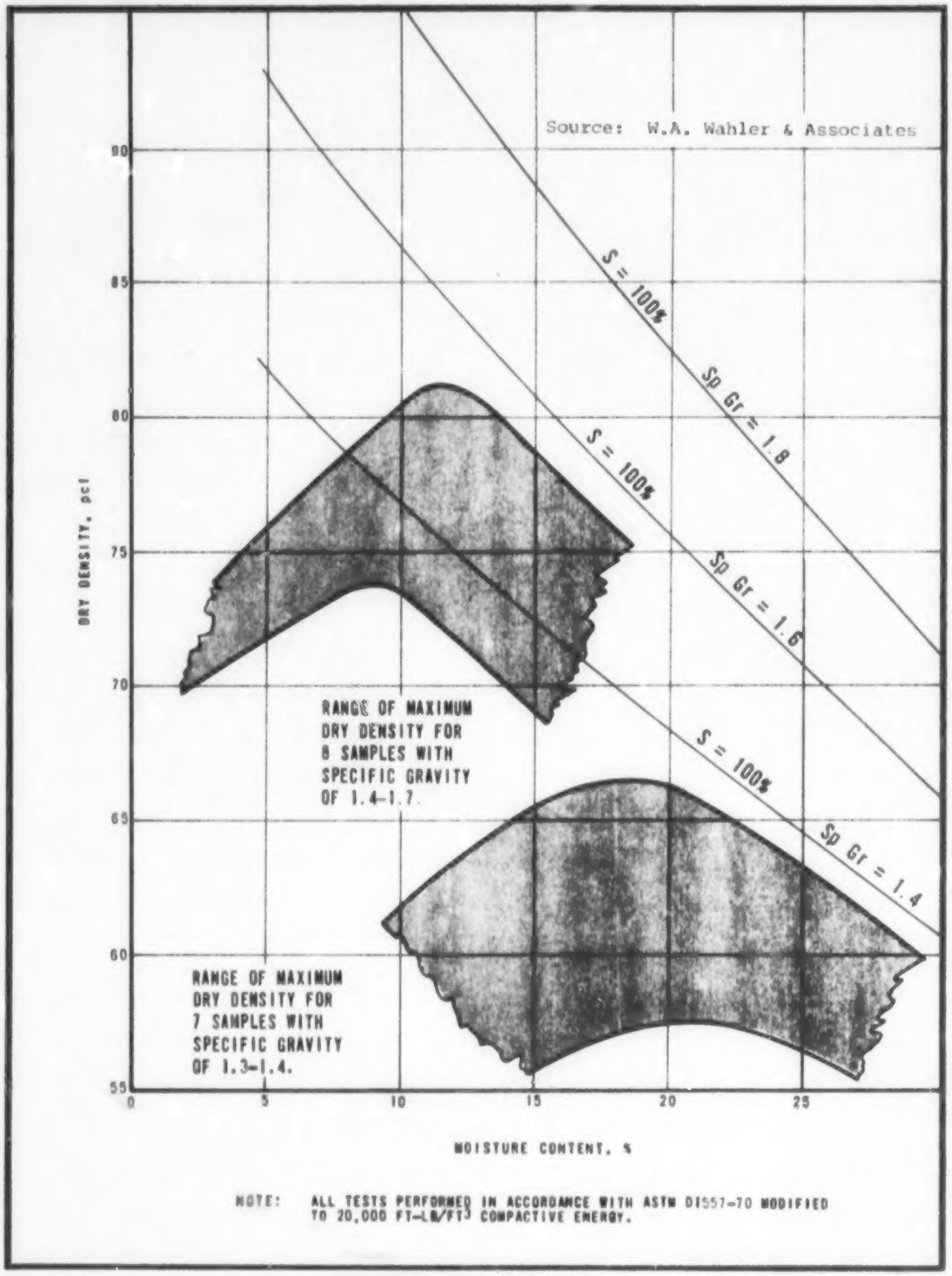


AVERAGE = 55.2 pcf

NOTE: THE DRY DENSITY DATA SHOWN HEREON ARE REPRESENTATIVE OF 78 SAMPLES OBTAINED AS EITHER IN-PLACE FIELD DENSITY OR UNDISTURBED TUBE SAMPLES FROM 8 SITES IN WEST VIRGINIA.

Source: W.A. Wahler & Associates

Figure 13-17 IN-PLACE DRY DENSITY
FINE COAL REFUSE



Source: W.A. Wahler & Associates

NOTE: ALL TESTS PERFORMED IN ACCORDANCE WITH ASTM D1557-70 MODIFIED TO 20,000 FT-LB/FT^3 COMPACTIVE ENERGY.

COMPACTION CHARACTERISTICS
FINE-GRAINED COAL REFUSE

Figure 13-18

results indicate that a maximum dry density between 57.5 and 66.5 pcf is achieved for a specific gravity between 1.3 and 1.4 and a range of 74.0 to 81 pcf is achieved for specific gravity values between 1.41 and 1.70.

When the range of in-place dry density values previously referenced is compared to the maximum laboratory densities, it is observed that the ponding methods being utilized to dispose of the fine refuse materials result in a relative compaction of approximately 75 to 85 percent; however, the in-place moisture content is 10 to 20 percent higher than the optimum moisture contents. If the fine-grained coal refuse is to be used as a construction material for water-retaining structures, the material could be compacted by the use of mechanical compaction equipment to higher densities than those determined for the in-place materials. However, regardless of the density to which the material is compacted, it must be recognized that the low specific gravity and resulting in-place dry densities could lead to piping or instability problems if the fine-grained material is not properly ballasted, or confined, by the heavier materials. On the other hand, the low permeability of the fine-grained material will be necessary to retain water. Most likely some form of zoned structure will prove to be optimal.

13.2.2.4.6 Permeability--The permeability characteristics of the fine coal refuse materials were determined by thoroughly reviewing the disposal methods and laboratory test results. This evaluation indicated that a significant degree of anisotropy is developed in the fine-grained refuse materials because of their method of disposal. The fine-grained materials in the field are found to be highly lenticular with stratifications varying from fractions of an inch to several inches in thickness. The finest-grained silts (ML) usually constitute the thinner partings, and probably reflect variations in inflow of the slurry. The ML materials exhibit a coefficient of permeability of about 10^{-7} cm/sec, whereas the fine- to medium-grained silty sand (SM) which constitutes the coarser fraction of the fine-grained material, has a maximum coefficient of permeability of about 3×10^{-4} cm/sec. The ratio of horizontal to vertical permeability for the fine refuse material was found to vary between 15:1 to 100:1, with an average value of approximately 25:1.

The National Coal Board of England reference indicates a range in the coefficient of permeability of 10^{-3} to 5×10^{-7} cm/sec in the horizontal direction, and 10^{-6} to 7×10^{-8} cm/sec in the vertical direction.

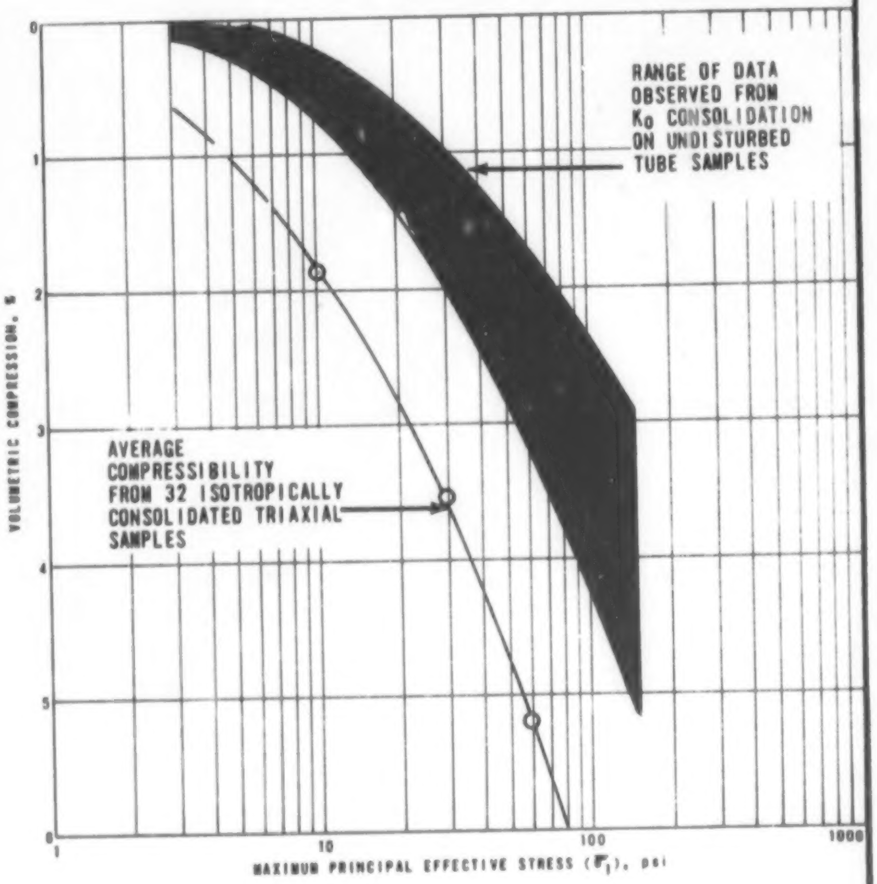
The high degree of anisotropy of permeability values for the fine refuse materials is extremely important to recognize when considering the stability characteristics of refuse impoundments, especially if the fine-grained materials form the foundation for an overlying coarse refuse embankment. The reason for the concern is that the relatively high ratio of horizontal to vertical permeability causes water to flow preferentially in a horizontal direction through these materials, thereby possibly transmitting high pore pressures to the toe of the embankment. The deficiency described above was shown to be a contributing cause in the 1972 failure of Dam No. 3 on the Middle Fork of Buffalo Creek in West Virginia.

13.2.2.4.7 Compressibility--The compressibility characteristics of the fine refuse materials were investigated utilizing triaxial test results. Because of the extremely low density and nonplastic characteristics of the fine refuse materials, it is very difficult to prepare samples for one-dimensional consolidation tests.

The results of compressibility from the triaxial tests are presented on Figure 13-19 in the form of axial strain versus maximum effective principal stress for samples consolidated under isotropic, as well as anisotropic test conditions. A range of volumetric compression of 2 to 4 percent was observed for the anisotropically consolidated samples, as compared with approximately 6 percent for the isotropically consolidated samples at 100 psi maximum effective principle stress. The initial dry densities for the above referenced triaxial samples varied from 52 to 64 pcf. These data indicate that the fine-grained materials are, in fact, less compressible than the coarse-grained materials referenced in the previous section. Again, it should be pointed out that the compressibility characteristics of the fine-grained material are not unusually high, and therefore these materials could be safely used as construction materials if proper construction techniques and adequate protection against uplift and piping potentials are incorporated in the design.

13.2.2.4.8 Shear strength--Shear strength parameters of the fine refuse material were determined from laboratory triaxial tests performed on 32 samples and are presented in Figure 13-20 in the form of shear strength versus normal stress for both effective and total stress. These samples consisted entirely of undisturbed tube samples and were tested under ICU test conditions.

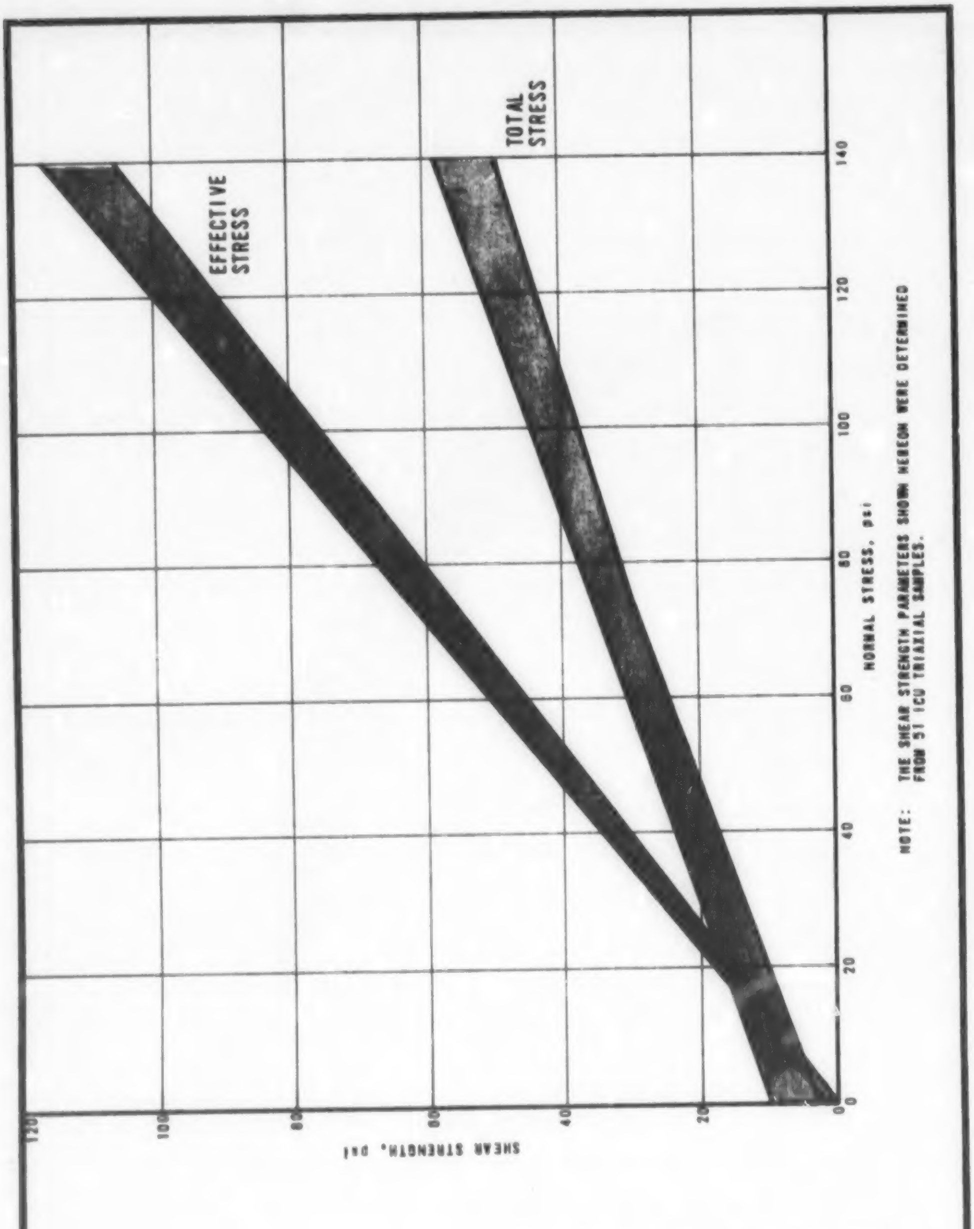
The shear strength results presented in Figure 13-20 indicate that the angle of internal friction, based on effective stresses, ranges from 37 to 40.5 degrees with little or no indicated cohesion, and that the angle of internal friction based on total stresses, is approximately 20 degrees with a cohesion intercept varying from 3 to 10 psi. The shear strength results of the fine refuse



Source: W.A. Wahler & Associates

COMPRESSIBILITY CHARACTERISTICS
FINE COAL REFUSE

Figure 13-19



NOTE: THE SHEAR STRENGTH PARAMETERS SHOWN HEREON WERE DETERMINED FROM 51 ICU TRIAXIAL SAMPLES.

Source: W.A. Wahler & Associates

Figure 13-20 SHEAR STRENGTH PARAMETERS
FINE COAL REFUSE

materials are remarkably consistent, considering the range in dry densities tested and obviously reflect the angularity observed in the fine-grained materials. As stated previously, the shear strength characteristics of the fine refuse materials also indicate a range in values consistent with other construction materials. In conclusion, although the low specific gravity and corresponding dry unit weight under any conditions of placement are not desirable physical properties for the fine-grained materials, it is possible to utilize them for embankment construction if these materials are properly confined or ballasted in order to maintain their stability against liquefaction and piping. Moreover, they may be essential in construction of impermeable layers or zones for impoundments.

13.2.2.5 Conclusions Regarding Physical Properties of Coal Refuse Materials The physical properties of coal refuse materials, which have been described and summarized above, indicate that these materials exhibit many characteristics that can be analyzed using conventional soil mechanics theory. Although the amount of published data available for this compilation is relatively small, those data presented represent a range of physical properties obtained from a number of different sites which constitute a cross section of industry-wide practices. As more sites are examined in detail, the amount of data regarding the physical properties of coal waste will increase and, when integrated with these data, will measurably increase the validity of the conclusions presented herein.

The coarse refuse material generally has adequate shear strength, permeability and compressibility characteristics consistent with other soil or rock construction materials which have been successfully used in the construction of earth and rockfill dams. It is also concluded that, using existing conventional earthmoving and compaction equipment, dams or dumps utilizing coal refuse as the major construction material can be constructed to similar design standards which currently govern the construction of earth or rockfill dams, though there will no doubt evolve significant differences as coal refuse engineering develops.

There are several aspects of the material behavior which require additional research, specifically, the influence of degradation of these materials caused by natural weathering or burning, and the effect of long placement times. Needed research should be directed not only toward an understanding of the physical aspects of weathering and the resulting influence of the degradation on the physical properties of the materials, but also on the techniques used in the engineering analysis of the stability and performance of refuse dams or dumps.

The fine-grained coal refuse exhibits unusually low specific gravities as a result of unrecovered coal which remains in the refuse slurry. However, these materials exhibit relatively high shear strength characteristics when compared to other fine-grained construction materials, and therefore, it is possible to utilize these materials for embankment construction when ballasting or confinement techniques are employed to maintain their stability against liquefaction and piping. Indeed, in some ways coal refuse materials may prove to be attractive as construction materials in non-mine related engineering construction.

A properly constructed dump or impoundment must be adequate in two principal ways: long term stability and environmental acceptability. A stable refuse deposit may not necessarily be environmentally acceptable. For example, highly acid water may drain in to a stream from an otherwise "safe" embankment. On the other hand, a waste deposit cannot be environmentally acceptable without also having long term stability. A properly constructed refuse deposit cannot be accomplished solely by good construction techniques. If careful site selection procedures are not used, if the concept of how the deposit will be formed and will perform are not understood and if the design is not properly carried out, sophisticated construction methods will be totally wasted.

13.2.2.5.1 Unique characteristics of coal refuse--There are several unique characteristics of coal refuse material. First and most important from a physical properties standpoint, is the abnormally low specific gravity of the fine refuse which averages about 1.5 (see Table 13-3) as compared with an average soil value of 2.65. As a result of the low specific gravity value, the resulting in-place dry density of the fine material, regardless of its method of disposal, is also very low, with average values of 50 to 70 pounds per cubic foot. The low density of the fine wastes can create two deficiencies: 1) at low density, the material cannot adequately resist the upward flow of water from an impoundment and, therefore, if placed in the foundation area without proper ballasting from heavier materials, it can create serious problems of internal erosion (piping), and 2) the low density may result in the inability of the material to mobilize an adequate effective stress to resist shearing forces. On the other hand, the low density makes the highly impervious fine material easy to transport, compared to ordinary soil.

The coarse coal refuse generally possesses a specific gravity more like that of a natural soil material. The coarse materials, however, contain flat, plate-like particles typical of slates and shales, which undergo rapid weathering to clay after the material has been deposited on the refuse pile. Also, if dumped in a loose fashion, the coarse coal refuse will have a high porosity (volume of voids) and tend to ignite by spontaneous combustion. The burning of the coarse refuse causes the material to fuse together, thereby resulting in a net volume reduction and the possible development of large voids in the materials during the burning process. Coal refuse and burned refuse, red dog, etc., also tend to weather faster than most other alluvial or residual soils.

13.2.2.5.2 Conveyance and placement--As discussed previously, it is the characteristics of the refuse that often dictate disposal techniques. Disposal, as well as construction, can be viewed as consisting of two operations--conveyance and placement. Coarse refuse is conveyed to the disposal site in a number of ways including: hauling in trucks over access roads, in cars on rails or on aerial tram systems, on conveyor belts, and sometimes combinations of more than one system. At times, coarse refuse is crushed and conveyed in a slurry with fine refuse in pipelines. Fine refuse is almost always conveyed in a slurry through pipelines to a disposal area, normally an impoundment. All of these conveyance techniques can still be used if they are used in the proper manner and if other techniques are used in the placement of at least some of the material so as to construct a stable deposit.

Final placement of materials in the structural elements--dams or retaining structures--will differ from placement by simple dumping. In the dump, spreading will usually be the only operation, whereas in the constructed element, spreading, zoning and/or compaction will follow placement.

Placement or dumping of coarse refuse is largely dictated by the conveyance method, although this is not a necessary result if economics indicate that a second handling of the material justifies using two methods to place material where it is to go, rather than changing entirely to another method. Truck hauling, which is probably the most common conveyance method today, is relatively flexible and all forms of dumps and retaining elements for impoundments, discussed below, can be built with flat slopes having some compaction with a minimum of rehandling, if the trucks are carefully routed.

Aerial tram operations in the past have been the least expensive conveyance method, but rehandling is necessary to obtain compaction and relatively flat slopes. Tram dumping is not as flexible as truck dumping, although suitable embankments can be built with the tram system. In practice, most aerial tram dumps become cross-valley inpoundments and many are enormous in size. Aerial tram operations will lose some of their economic advantage if material must be rehandled to construct flatter slopes and to obtain a degree of compaction, although they can be used to transport materials to the site for construction of the retaining structure and to dump material in the storage area behind the retaining structure if properly planned as part of the system.

Conveyor belts almost always require rehandling of the materials. In addition, conveyor systems are relatively inflexible, although continuing development is producing more portable systems. With the necessity of constructing coal refuse embankments with improved stability characteristics, relocation of materials may be necessary for more systems and conveyor systems may come into greater use.

Rail handling systems were relatively common 30 to 50 years ago. They are the least flexible and are seldom used today on a large scale. Slurry disposal in a reservoir, where the solids can settle out or the water can be filtered out through a stable filter-retention structure, is and will reamin the most economical method of fine refuse disposal at most plants.

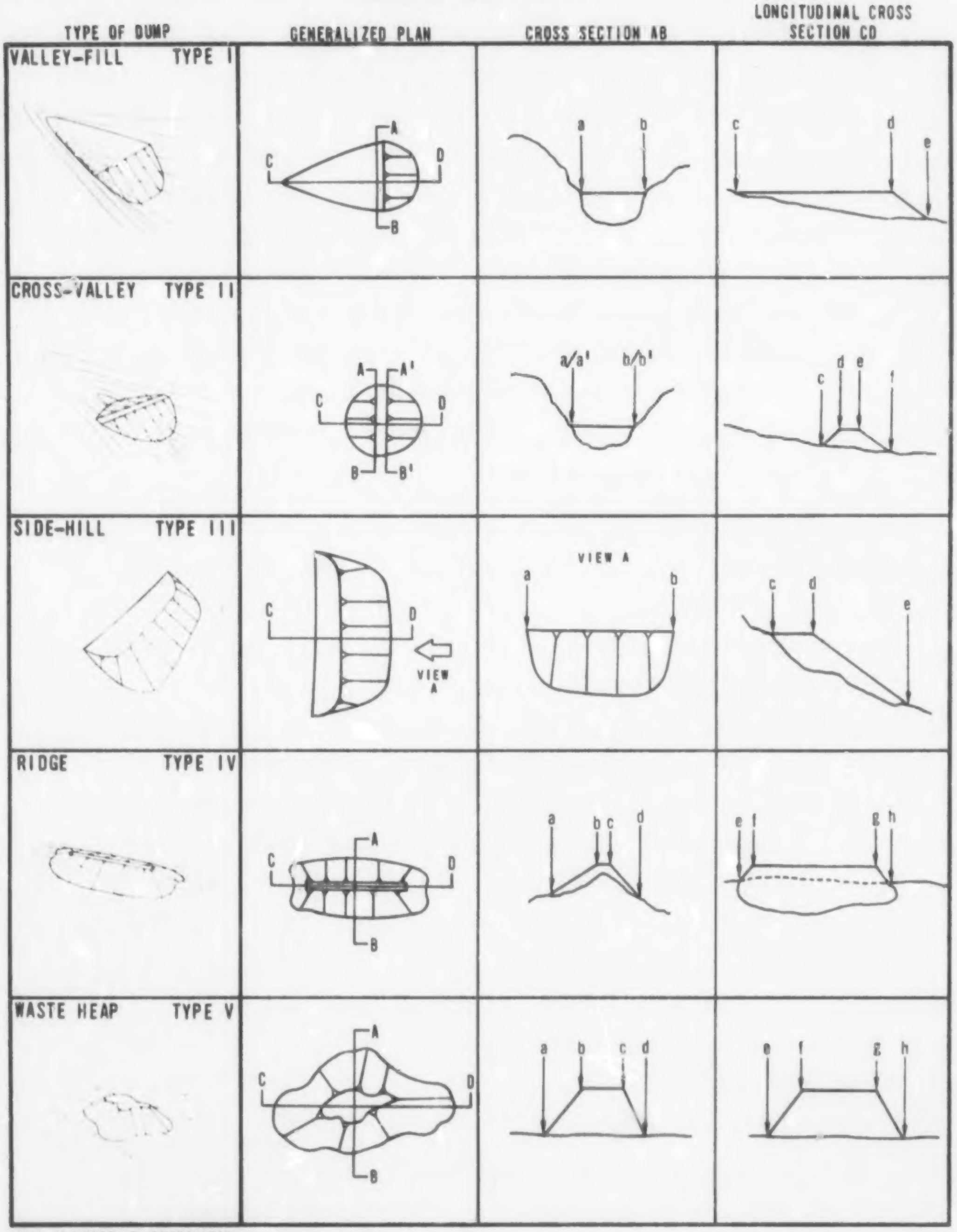
13.2.3 Types of Refuse Deposits

In order to facilitate communication on an organized basis, a classification system for coal refuse deposits, as developed by W. A. Wahler and Associates, is included as part of this manual.

A refuse dump is a permanent or long term accumulation of mine, mill or plant refuse materials including low grade coal, development rock and other products left over after mining and processing of coal. A dump can be on or in the earth and is not capable of impounding fluids. Dumps have accumulated on a variety of land forms and assume various shapes depending upon the original land forms, the type of material disposed of and the equipment used for disposal. Figure 13-21 portrays the simple dump forms discussed.

13.2.3.1 Ridge Dumps ·In some cases, coal refuse materials have been dumped along ridge crests so that the refuse materials reached their angle of repose on both sides of the ridge. This type of dump is usually constructed by dumping from cars off a rail system or by use of dump trucks. Because the material falls downhill to its angle of repose, a low margin of safety is developed; as the deposit grows, local or gross instability can result, and sooner or later a stability condition determined by the foundation materials will develop. This

SIMPLE DUMP FORMS



W. A. WAHLER & ASSOCIATES

Figure 13-21

type of deposit does have certain elements that tend toward stability because as material is dumped, natural sorting takes place as the coarser material tends to roll further, coming to rest near the base of the slope. The resulting configuration provides stratification of material parallel with the slopes and reasonable drainage characteristics that will tend to keep water from building up in the dump. If instability develops, treatment is often difficult because usually the material is spread thinly over a large area and a large amount of material may need to be moved to improve its stability. This type of dump is particularly susceptible to both long term creeping failure and catastrophic failure.

13.2.3.2 Side-hill Dump A side-hill dump is similar to a ridge dump except the deposit is on one side of a ridge or hill. This type of dump is often constructed by dumping off the side of a hill with mine cars or trucks, although other techniques also are used. Stratification of materials may also develop, as with the ridge method, but may not be as pronounced because considerable dumping may take place on the flat surface that develops at the top of the deposit and the dump is usually thicker than the ridge dumps. The side-hill dump is one of the most common types of dumps. If the dump is unstable and the mass of material involved is large and if it is located adjacent to a flowing stream, it can slide across the drainage course causing water storage behind the failed portion of the dump with the potential for sudden release of the stored waters when the "slide" dam is overtopped.

13.2.3.3 Cross-Valley Dump This type of dump, as the name implies, is built across a valley or stream course. The deposit is rare because in practice it usually is capable of impounding liquids and becomes a cross-valley impoundment--which is very common. This type of dump is usually very coarse-grained; therefore, the rate of permeability is high and it is prevented from impounding water because the outflow potential is equal to or greater than the inflow potential. Without the capability of impounding liquids, a cross-valley dump is generally a low hazard deposit, although slopes can be unstable and subject to sliding. It may also become an impoundment during a severe storm condition, or if it becomes clogged by silt and loses its permeability.

13.2.3.4 Valley Fill Dump When a cross-valley dump or impoundment completely fills a valley and has no capability of impounding liquids, it becomes a valley fill dump. Valley fill dumps may be very large volume deposits; they can be environmentally very acceptable, providing erosion control measures are adequate. This type of fill may be the most acceptable dump because it is in a form that is relatively easily stabilized and abandoned; a large flat surface can be made available for new uses after refuse disposal ceases.

13.2.3.5 Waste Heap A waste heap, as the name suggests, is a pile of refuse and is most often formed where local terrain is relatively flat. It can be built with a range of equipment types. Because it lacks the capability to store liquids during its entire development, it can be a low hazard type of deposit if its slopes are adequately flat and graded so as to be stable. Aesthetically, a waste heap could be poor unless extensive revegetation and landscaping measures are taken.

13.2.3.6 Complex Dump This category of dump is used for a deposit that consists of more than one of the basic shapes such as a complex side-hill cross-valley dump or one which consists of so many combinations of other types as to defy description with a combination term. Many large deposits have a very irregular shape and are best described as "complex". Complex dumps develop when the mode of operation has changed and disposal techniques are modified as the dump is enlarged or when a very large amount of material must be spread over an irregular landscape. Dumps with a variety of forms may be difficult to analyze in an engineering sense, because it is very difficult to determine material properties and distribution and to establish with certainty which sections are most critical. Thus, their hazard potential and environmental acceptability may be difficult to evaluate with a high degree of assurance.

13.2.4 Construction Techniques Proposed for Consideration

Many new construction techniques will be required to reduce existing hazards and to minimize hazards at new disposal sites. The current concern for environmental effects will place a greater pressure on the coal industry to develop new and acceptable procedures. In addition, new engineering practices will have to be developed to deal with some of the unusual properties of coal refuse. Both research and active experience must be developed with emphasis being placed on modification of existing deposits so that they may be converted to other uses and on the planning of new sites so that they can be readily abandoned and permitting new uses of the disposal areas.

Much of the equipment presently used for coal refuse disposal is adaptable to the application of new techniques. Some equipment which is not commonly used by the coal industry should be considered for wider use, including earth compaction, moisture conditioning and screening and grading equipment for material size selection.

13.2.4.1 Modification of Existing Deposits

Described below, with an emphasis on construction techniques, are some of the ways that existing deposits can be made more acceptable. Use of modern engineering analysis is pre-supposed as essential to modification of construction practics.

13.2.4.1.1 Active deposits--Present construction practices encompass the use of most of the equipment and procedures needed for modification of inadequate slopes and graded embankments. For minor slope repairs and grading, the bulldozer is the most adaptable. However, bulldozers become inefficient when large quantities of materials are moved relatively long distances, and equipment not commonly used on dumps (such as scrapers, loaders and trucks) but presently used elsewhere on the mine property should be considered for large dump degrading operations.

For spreading refuse dumped from trucks or tram lines, bulldozers are effective, but scrapers should also be considered. The spreading of refuse into layers should be encouraged, even though little compaction is achieved, because the exposure of refuse to air promotes oxidation and reduced combustion potential upon burial. This is particularly effective if active disposal areas can be alternated, thus affording longer exposure. By alternating disposal areas, equipment can be more easily routed across embankment surfaces, thus achieving a further degree of compaction.

Combustion control on an active deposit can begin with some of the construction techniques described above. Further, construction equipment is usually present on a refuse disposal site, and often a widespread fire can be prevented if the development of hot spots is noted, and immediate sealing and surficial wetting measures are initiated at a smoldering location on the embankment.

13.2.4.1.2 Inactive deposits--Some deposits are operated on an occasional basis and some are abandoned for a while to be reused when again convenient. These are inactive deposits where the operation may begin again at some unknown time. Full abandonment is not planned, but operations have been suspended. Maintenance on such deposits is difficult because they have not been protected for long term self-maintenance, and yet are not kept up by daily operation. A proper program of maintenance and observation will be necessary to keep such deposits in proper repair.

13.2.4.1.3 Abandoned deposits--Every effort should be made to find suitable uses for abandoned coal refuse disposal sites. A number of successful reclamation or reuse projects are reported each year. Such an effort will improve the image of the coal industry and in some cases, may prove profitable to the company. Many old and burned out refuse piles serve as quarries for red dog, which is used for many purposes in the mining areas of Appalachia. Care must be exercised in mining red dog because several people are killed each year trying to mine this material by excavating from the downhill toe. Because the material is relatively stable, they are often able to mine it until quite a high and steep cut is made. Failure of the cut often comes suddenly and with lethal results.

Existing abandoned sites may require the construction of some measures to minimize their hazards and improve their environmental acceptability. The coal industry has, for some years, been developing equipment and techniques for seeding exposed slopes, particularly in strip mining operations. Many new procedures, some of them fairly inexpensive, are becoming available through use of soil chemistry and agronomy, whereby slopes can be graded or treated with certain materials or chemicals that can maximize revegetation efforts. Other construction procedures such as rolling of slopes could be used to minimize erosion. Many new erosion control techniques are presently being developed through research and experimental demonstrations.

13.2.4.2 Proposed Deposits Construction of new coal refuse deposits can be most satisfactorily and economically accomplished through adequate site selection, design and construction techniques with an emphasis on an overall plan leading to a suitably abandoned refuse facility. Earth dam technology provides the basis for constructing zoned refuse dumps. Since often the only construction material available is coal refuse, the material can be mechanically graded so that materials of different gradations are made available. Grizzlies and screens used in coal processing can also be used for coal refuse grading. Many operations use grading techniques for coal processing and, in some cases, the grading used for processing could be utilized for refuse disposal if the materials are not remixed prior to disposal. Refuse dumps could then be constructed by placing graded zones, internal drains and filters for better stability characteristics.

Earth dam construction technology also offers construction control procedures, whereby moisture conditioning and testing procedures are used to determine whether compaction techniques are effective and the desired results are being achieved.

If relatively sophisticated techniques for embankment construction are used, they should be adequately controlled by surveying techniques that help monitor the position of the elements of the embankment as it is being constructed. The performance of the embankment during construction and later can also be monitored with instrumentation which is installed during construction. Instrumentation equipment and devices available include piezometers, surface and subsurface settlement markers, slope indicators and others with relatively sophisticated applications.

13.2.5 Types of Refuse Impoundments

An impoundment is a permanent or long term accumulation of mine, mill or plant refuse, on or in the earth, that is capable of impounding liquid. Impoundments associated with coal refuse disposal have been used as settling and filtering facilities and to store fine coal refuse (sludge/slurry). Other coal refuse impoundments serve as storage for coal processing plant water. Water may also be stored without intent to store; this type of facility is still termed an impoundment. Some impoundments serve the dual purpose of acting both as settling ponds and as water storage facilities. Even though a given facility normally does not store liquids, it is an impoundment if it has the potential to impound, that is, if during a flood, water can build up in the retaining portion of the facility.

The ponds that develop on most tailings deposits serve multiple functions: to provide for collection and storage of water in water-short areas, and to provide a settling pond to remove suspended solids from the tailings before the water is reclaimed or disposed.

These are the useful aspects of the ponds. There are also a number of undesirable aspects to them, including the following: 1) in the event of an embankment failure, the ponds provide a quantity of liquid to enlarge the volume of material flowing downstream, thereby providing greater erosion and carrying capacity to the material involved; 2) the more water involved in a flowing mass, the further it can flow; 3) the pond provides a constant source of water for saturation of the mass of tailings and, in many cases, at least partial saturation of the containing embankment. This increases the probability of liquefaction failure under adverse conditions and lowers the strength of the embankment below the phreatic surface even under normal conditions; 4) the disposal capacity of a structure is reduced by the volume required for the pond; 5) the consolidation of the materials below the phreatic surface is reduced due to the buoyant effect of water below the surface of saturation (phreatic surface); and 6) the pond provides a source of water that can infiltrate into the ground, degrading naturally-occurring ground water. Figure 13-22 displays the simple impoundment forms.

13.2.5.1 Cross Valley Impoundments This type of impoundment is one of the most common types in regions with steep terrain. Cross-valley impoundments are often very large, and are particularly subject to flood hazard problems because watersheds are often relatively large. A very large precentage of the cross-valley impoundments in the Appalachian region were considered inadequate in 1972 from the flood hazard standpoint. Many had inadequate or no spillways or other flood bypass facilities. A considerable number could have stored floods of record, but the impounding element (dam) often would have been structurally inadequate to store such a large volume of water and would fail due to application of seepage forces before it could be overtopped.

Cross-valley impoundments are constructed by several methods. The most common methods are by dumping from

SIMPLE IMPOUNDMENT FORMS

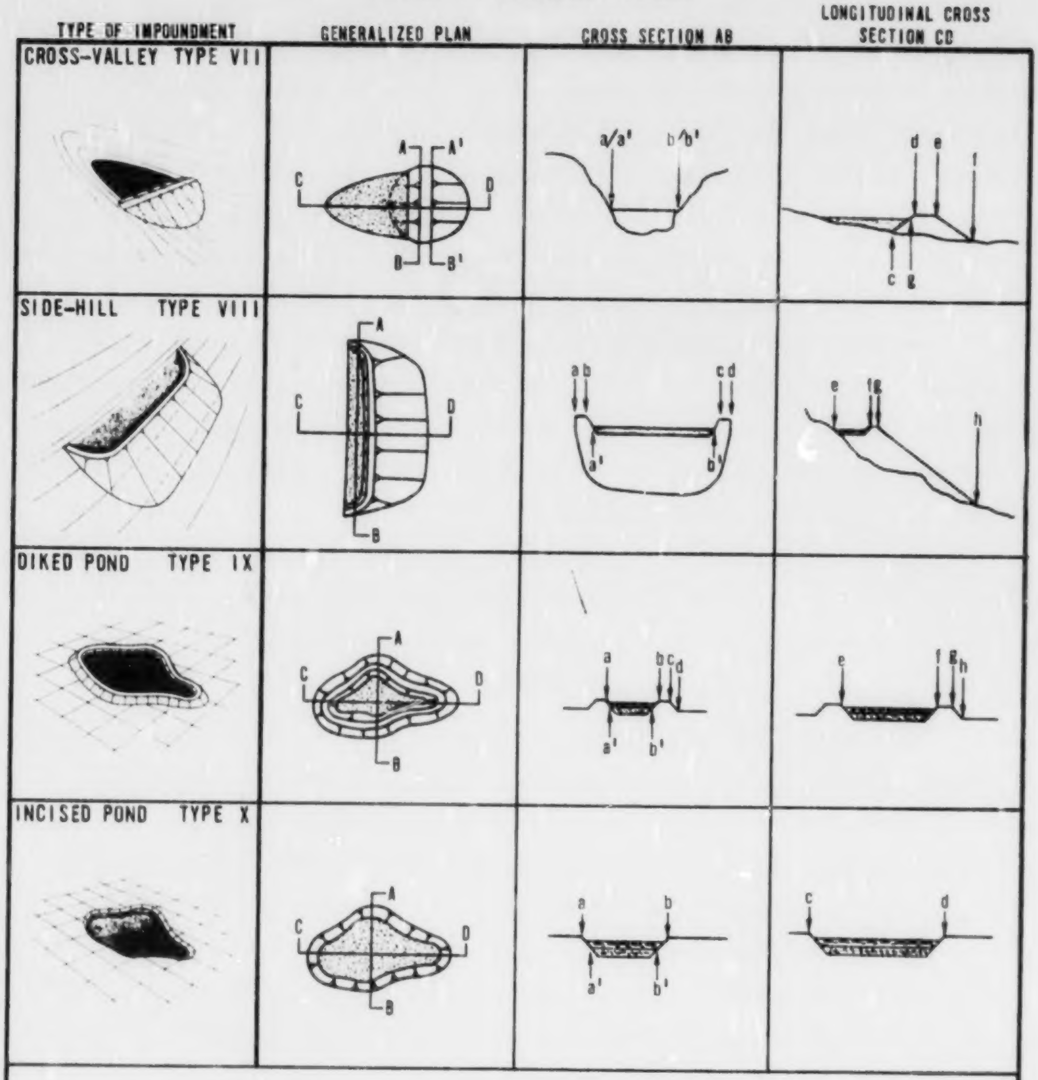


Figure 13-22

W. A. WAHLER & ASSOCIATES

aerial tram cars, whereby the deposit rises with an approximately horizontal or inclined crest across the entire valley; or dumping by trucks, whereby the crest level may be highly irregular along its length. Aerial tram construction does not normally receive compaction of any sort; truck-dumped fills receive some compaction by equipment passage, particularly if some effort is made to vary travel routes, but even this compaction is cosmetic rather than real unless the lift thickness and moisture content of the material is controlled and the equipment haul carefully regulated.

13.2.5.2 Side-Hill Impoundments Another very common type of impoundment normally used to store sludge is the side-hill impoundment. Most of these facilities grew over an older side-hill dump. Although side-hill impoundments generally have relatively smaller drainage areas and thus are not subject to as great a flood threat as cross-valley impoundments, they are often constructed with too thin and too steep embankments, and are particularly subject to piping failures and slope failures. Retaining embankments for side-hill impoundments are usually constructed by truck hauling and dumping. Some side-hill embankments and attendant impoundments grow to enormous size, although they seldom rival the size of the largest cross-valley impoundments. One of the bad aspects of this type of impoundment is that it often keeps a large portion of the entire deposit saturated, thus lowering the general stability of the structure, as well as the impoundment area itself.

13.2.5.3 Diked Pond Diked ponds are generally only built where flat topography is available. They are simply constructed by building a dike around the pond area. Usually they are best adapted to truck operations. Where diked ponds are kept small, they usually do not pose great hazards, but seldom do they aesthetically fit well into the environment because of their long exposed dikes.

13.2.5.4 Incised Pond Incised ponds are least subject to creation of potential hazards because they are constructed below existing ground levels. Usually material that is excavated from the pond area is used to construct dikes. Therefore, in practice, an incised pond often becomes a combination of a diked pond and an incised pond. Obviously, to obtain a large storage volume, a large quantity of material would need to be excavated and disposed of elsewhere to matintain a pond in a strictly incised pond state.

13.2.6 Construction Techniques for Impoundments

Many of the construction techniques used prior to Buffalo Creek were actually highly innovative and large volumes of materials were moved at very low cost. The main problem was that the practices involved only minimal considerations of environmental adequacy and hazard mitigation. Sometimes, this consideration could have been achieved at very low cost and with satisfactory results if consideration had been given at the proper time to be effective.

A few valley fill embankments have been constructed that have reasonably adequate drainage; these facilities were revegetated and were available for other purposes as land uses changed. Their hazard potential was usually very low and confined to a very narrow and low-lying area.

Some operators mix coarse and fine refuse, normally resulting in solid embankments and obviating the need for an impoundment. Several variations of mixing operations have been used. Some operators pipe slurry to a series of small ponds, the use of which is alternated so that drainage takes place from previously used ponds. After water has drained, the ponds are dipped and the partially dried slurry trucked to a coarse refuse deposit. Another method is to thicken and dewater the slurry at the plant. The coarse and fine refuse are then mixed and carried to the refuse deposit by truck or aerial tram. Still another method used to obtain a degree of mixing is to form small impoundments by excavating and diking on a coarse refuse dump. Slurry is pumped into these small impoundments and then covered with coarse refuse when the ponds are full, thus at least partly mixing the refuse or at least dispersing the fine-grained material throughout the mass of the dump. Although some "mixing" operations produced high hazard disposal sites, in general, hazards are considerably lower at operations where one of the mixing procedures is used.

A few operators achieve relatively low hazard disposal dumps and impoundments, although they may be relatively poor from an environmental standpoint and therefore difficult to abandon. For example, some construct many small side-hill dumps rather than one or two large dumps or impoundments. Although such practice is unsightly, hazards can be kept to a minimum. Other operators construct very large flat-sloped and wide-crested embankments that can safely store very large floods. Some of the resulting impoundments have low hazard potentials, but these facilities have almost always had severe environmental problems and are most difficult to abandon adequately. Thus, safety and environmental suitability must be planned and achieved in concert, rather than as separate objectives and operations. Unfortunately, just which combinations are best has yet to be established. Several examples do exist where coal refuse deposits were graded to drain properly, were revegetated, had long term stability and environmental suitability and were made adequate for other uses. Unfortunately, prior to the Buffalo Creek disaster, most coal refuse disposal techniques were inadequate in some way from the standpoint of hazard minimization as well as environmental suitability.

Probably the most widespread hazardous practice involved failure to recognize potential flood hazards; where coal refuse embankments were constructed across streams without providing adequate flood bypass facilities.

Disposal of coarse refuse at its angle of repose was standard practice at most operations. Most embankments were constructed this way regardless of the mode of conveyance or placement, the resulting form of the embankment or the strength of the foundation.

Sometimes, during placement, coarser materials can be concentrated near the downstream toe of an embankment with a minimal change in construction procedure. This should be encouraged, as better drainage characteristics of the embankment will result and the stronger material will be at the toe where it will do the most good.

Many coal refuse impoundments are enlarged by pushing coarse material over the impounded sludge and increasing the height of the embankment. This procedure may be desirable if abandonment is close at hand, but such a construction method must be understood and properly used, recognizing the characteristics and limitations of the materials utilized. If the strength characteristics of the embankment are to be improved, downstream slopes need to be flattened and weight increased at the toe by construction of buttress fills.

Often a relatively minor adjustment can be made in sludge disposal to improve some impoundment's characteristics. Sludge can be discharged near the face of the embankment. Through natural sorting, the coarsest material will settle near the embankment, and fines and water will be driven into the upstream portion of the impoundment. This procedure is especially to be recommended if the upstream method of construction is to be used. Using a multiple discharge system would further increase the natural sorting process. Where coarse material is lacking, cyclones can be used at the pond to separate materials on the basis of size to assure placement of the coarser material where its favorable structural characteristics will be most useful and the fine material where it will not constitute a hazard. Actually, such practices are the first step in initiating systems whereby sludge is mechanically sorted and used as a construction material in a zoned embankment similar to techniques practiced in the metals mining industry.

Strip mining practices produce some of the finest rock excavations seen anywhere. This technology is available to the coal mining industry for construction of cuts in rock for spillways where flood bypass facilities are needed.

Even with the best practices and construction techniques, occasionally an emergency can develop. If an emergency plan is drawn up before an emergency develops, construction equipment available on the site can be effectively rallied to prevent or mitigate a disaster. For example, if a boil forms on the face of an impoundment dam or dike, it could develop into an embankment failure unless quickly arrested and should, therefore, be considered a serious condition. If equipment operators and plant personnel know what is expected, control measures can be initiated, such as immediate placement of reverse filters if material is available or placement of rocky materials if filter materials are unavailable. Use of piezometers to detect excess pore water pressure will help prevent emergencies and allow for economical placement.

With careful planning and design, advantage can be taken of how liquid or semi-liquid sludge relates to the impounding embankment and sufficient area to avoid constructing by the upstream method can be provided. Additionally, starter dikes usually constructed of low permeability materials can be incorporated into the remaining embankment so that a high phreatic surface is not created. Where a high phreatic surface will be created by an impervious starter dike, the dam must be able to withstand the pressure or consideration should be given to deliberately designing and constructing a previous starter dam which will preclude buildup of a high phreatic surface in the dam or dump. In either event, the practice must be to determine what is to be achieved and to achieve that result rather than to follow a "standard" practice without understanding its probable performance characteristics.

Many new impoundments can be planned so that spillway construction costs can be minimized. Spillways can be constructed at succeeding elevations as impoundments are brought up. In some cases, disposal sites can be adapted to a dual spillway concept which incorporates a service spillway to carry unusual runoff. If the embankment is properly constructed and can retain the design flood, drainage ditches with their attendant problems can be omitted.

13.2.7 Surveillance, Maintenance and Abandonment

Coal waste dumps and impoundments must be maintained or they will deteriorate and create safety or environmental problems. When abandonment is contemplated, the deposits must be prepared so that they will maintain themselves in a manner similar to the adjacent natural materials or they will cause lasting problems for everyone concerned. It is desirable that the deposits maintain themselves as compatible as possible with the rest of their environment--neither degrading faster than the natural material in the vicinity, nor being grossly more resistant to natural processes than is the adjacent natural material.

Surveillance by direct and instrumental observation is necessary to monitor the condition of deposits prior to abandonment and to assure that maintenance is accomplished when needed and to assure that the maintenance is adequate to control local problems before they develop into serious matters. Surveillance also can monitor slope or deposit degradation during operation so as to provide a basis for estimating the type, nature and rate of degradation to be used either for design of abandonment measures or for concluding that abandonment can be made without undue modification or trouble.

Routine surveillance and maintenance of operating and inactive deposits is also necessary to detect and minimize or remove hazards on both dumps and impoundments. Waste deposits can only be maintained in a safe manner through systematic and continuous monitoring of the deposit conditions. A specific surveillance program has proven to be considerably more effective than undefined haphazard observation; moreover, only a skilled engineer understands the mechanics of slope stability.

Surveillance and maintenance are also required to detect and prevent air pollution through dust and combustion control and to evaluate and reevaluate construction and dumping procedures in order to keep them effective, efficient and economical, as well as keeping the deposits safe and environmentally suitable.

In summary, the reason for establishment of routine surveillance and maintenance procedures for coal refuse deposits is largely to prevent hazardous practices or conditions from developing or continuing. In other words, they are preventative measures that, if properly planned, will achieve the following goals:

- prevent development of hazardous operations or conditions;
- control air and/or water pollution;
- result in more effective and probably less expensive refuse disposal (if costs of failures, emergency repairs or required restructuring of deposits are considered); and
- incorporate, or lead to, an abandonment procedure that will require little or no maintenance or surveillance.

A routine maintenance program is required during the active period of refuse disposal and during the period of implementation of an abandonment plan. Ideally, after a deposit is abandoned, no further maintenance is required. However, in practice, maintenance should taper off as slopes achieve a stable inclination, vegetative cover is more permanently established, erosion controlled and the deposit becomes a stable portion of the environment. Nonroutine maintenance includes repairs or measures to rectify unforeseen conditions such as a slope failure or an outbreak of burning.

It would be impractical to require an operator to maintain a maintenance program after abandonment in most cases. A more practical solution is to require abandonment procedures that will need little maintenance and will encourage establishment of other land uses such as home and commerical sites, recreation, grazing, etc., that will maintain stable conditions. Title to the land after abandonment can be transferred to other ownerships and other uses that should be responsible for the use and condition of the land. The operator should be responsible for creating a condition that is attractive to other land uses.

Even with an enlightened approach to land reuse by coal companies, a procedure for transferring surveillance responsibilities to appropriate agencies after abandonment may be needed. These agencies might include a number of state agencies, such as: the Soil Conservation Service, Public Health Service, etc. After an operator declares a site abandoned and tentative approval is given, surveillance should be continued by the operator long enough to reasonably judge whether or not the abandonment procedure is effective. The main point is that some vehicle is needed to keep a watchful eye, even after abandonment of a properly constructed refuse deposit.

13.2.7.1 Surveillance Surveillance techniques can be separated into routine visual inspections and special site monitoring incorporating instrumentation results and other sophisticated monitoring techniques. Routine surveillance should be performed by responsible company personnel, as well as regulatory agency inspectors, who are familiar with factors that cause hazardous and environmentally degrading conditions. The big advantage of coal company inspections is the day to day familiarity with site conditions as they develop. Also, there should be no need for more than quarterly or bi-annual inspections by agency personnel, if the facility is properly inspected, documented and maintained by company personnel.

Special monitoring of a refuse deposit is required when the deposit has been allowed to develop in an uncontrolled manner and/or where signs of instability or environmental degradation are detected. Where such conditions exist, data from instrumentation arrays may be required to adequately judge the condition of the deposit. The selection and installation of instruments must be performed by or under the supervision of a person experienced in the techniques. This type of monitoring may have a limited duration, if the structure is determined to be performing satisfactorily and abandonment is complete. However, other monitoring objectives such as water quality or internal termperatures might require activities for indefinite periods. Interpretation of the results of specialized monitoring data usually requires sophisticated techniques of analysis. For example, if the purpose of instrumentation is to determine stability, the study must be performed by an experienced and competent soils engineer.

Good surveillance and recording techniques can add to the body of knowledge concerning the performance of embankments and impoundments. The recorded performance should be compared to the performance anticipated during the design and analysis phase. The designer needs to know how the facility is performing so he can formulate modifications if necessary. He also needs to protect his client's investment, as well as his own reputation. Sometimes embankments do not perform as intended, because unforeseen difficulties can develop even though the design was done according to current standards of practice. At other times, a facility is not constructed as intended because of improper procedures which can be honest mistakes. Further, conditions can change after the facility is constructed through some natural or man-induced process. Surveillance provides an element of protection for everyone involved.

Legislation currently under consideration will most probably broadly modify the Coal Mine Health and Safety Law, and it may put abandonment under the proposed Mined Area Reclamation Act. In any case, the coal companies will be required, among other things, to perform strict surveillance procedures on designated coal waste deposits.

Federal legislation has defined the responsibilities of the Mining Enforcement and Safety Administration (MESA). These responsibilities were formerly part of the U.S. Bureau of Mines' activities. This authority, under the 1969 Federal Coal Mine Health and Safety Law charges MESA with conducting routine surveillance inspections. If conditions are not considered satisfactory by the District MESA office, the Technical Support Centers, as well as outside consultants, can be called upon to furnish assistance. With this program hopefully hazard mitigation can be achieved before major hazards can develop.

The 1972 National Dam Safety Act (P.L. 9L-367) provides for a national dam inventory program to be administered by the U.S. Corps of Engineers. Under this porgram all dams, including mine refuse impoundments that fall under legal definitions of a dam, will be surveyed. Eventually, regular inspection and surveillance will be initiated for control of potential hazards under the new law. This may be accomplished directly by the U.S. Corps of Engineers, the individual state or MESA.

Surveillance by regulatory agencies has two basic objectives: 1) to inspect facility conformance to an acceptable plan and 2) to inspect facility performance. An additional objective is to see that documentation of the history of the deposit is maintained for later reference if problems develop. Facility performance should determine the need for changes in routine maintenance procedures, for remedial work and, of course, for emergency action if hazardous conditions develop.

13.2.7.2 Embankment Surveillance and Instrumentation Surveillance as used herein is defined as the routine visual inspection of a structure's performance as well as the systematic collection, analysis and interpretation of data obtained from various types of instruments installed within a dam to aid in monitoring and evaluating the performance of a structure. Routine surveillance should be performed by responsible company personnel, as well as regulatory agency inspectors who are familiar with factors that cause hazardous and environmentally degrading conditions. The big advantage of company inspections is the day-to-day familiarity with site conditions as they develop. Also, there should be no need for more than quarterly or bi-annual inspections by agency personnel, if the facility is properly inspected, documented and maintained by company personnel.

Good surveillance and recording techniques can add to the body of knowledge concerning the performance of embankments and impoundments. The recorded performance should be compared to the performance anticipated during the design and analysis phase, or with a developed historical record of structure response. By using the knowledge gained, a more precise, and hence more economical, design may often be developed.

Special monitoring of a tailings or leach dump deposit is required where it was allowed to develop in an uncontrolled manner and/or where signs of instability or environmental degradation are detected. Where such conditions exist, data from instrumentation arrays may be required to adequately judge the condition of the deposit. The selection and installation of instruments must be performed by or under the supervision of a person experienced in the techniques. Interpretation of the results of specialized monitoring data usually requires sophisticated analysis. For example, if the purpose of instrumentation is to determine stability, the study must be performed by an experienced soils engineer.

13.2.7.2.1 Surface Monuments The installation techniques for a monument included the setting of a 3- or 4-foot long section of rebar into a 12-inch diameter by 12-inch deep concrete collar. This method of installation is relatively fast and inexpensive. Two men can easily install 8 to 10 or more monuments in one day.

The total number of surface monuments will vary at each site depending on the size of each dam and the method of construction being used. For example, on any dam being constructed by the upstream method, surface monuments should be installed on each major bench at the quarter points (distance between each monument equal to approximately 25 percent of the total berm length) if the berm is less than 600 meters in length, the fifth points (20 percent of the total berm length between monuments) if the berm length is between 600 meters and 1500 meters in length, or at 300 meter stations if the berm length exceeds 1500 meters. If the dam is being constructed by the downstream or centerline method however, the installation of surface monuments cannot be completed until each time that a berm has been constructed which usually occurs near the end of complete construction.

The time interval of readings of surface monuments for tailings dams being constructed by peripheral discharge methods can be scheduled to provide a maximum amount of information. Survey readings should be scheduled such that three or four sets can be obtained at equal time intervals during deposition and then at monthly intervals after the pond has been filled until it is observed that any major horizontal and vertical movements due to pond filling have ceased. It is convenient to plot the resulting data on semi-logarithmic paper (one leg cycle by 70 divisions) with the time in days from point of first filling as the abscissa and settlement and/or horizontal movement in tenths of foot as the ordinate. Long term monitoring data for each monument should be plotted on an arithmetic grid with settlement or horizontal movement vs day of the year. Significant data regarding the loading history, such as day of first and final filling of a pond, should be superimposed on both graphs referenced above to aid in the interpretation of resulting data.

13.2.7.2.2 Piezometers Although open well piezometers are often used in monitoring refuse dams, this type of piezometer does not respond quickly enough to changes in pore pressure to be used in tailings dams. The use of pneumatic piezometers is preferred because of their more rapid response time.

With regard to locating piezometers in the field, it is better to select certain areas of the dam as test sections and concentrate instrumentation efforts rather than randomly installing a number of instruments throughout the deposit. The number of test sections required will, of course, vary depending on the size and type of the structure to be instrumented and the method of construction; however, two test sections having three to six piezometers each should be considered as a minimum. For tailings dams being constructed by the upstream method, a typical pattern of piezometer location at each test section may consist of the following:

- Existing Tailings Dams--For existing tailings dams, the piezometers should be installed on a bench located at less than one-half the height of the structure. The piezometers should be placed using a down-hole technique at an approximate elevation corresponding to the one-third and two-thirds height of the dam as measured from the berm elevation to the foundation. This installation technique should be repeated at approximately 50-foot height intervals.
- New Tailings Dams--The installation technique and number of piezometers to be used in a new structure is dependent on the construction method to be used. For dams using a centerline or downstream method, it may only be necessary to install several piezometers in the downstream half of the embankment in order to determine the location of the phreatic surface with regard to the foundation contact or drainage collection system (if used). For new dams using an upstream method, a technique similar to that referenced above for existing dams should be considered except that at approximately 50-foot height intervals, piezometers should be installed at a depth of 10 and 30 feet in each of two holes located about 100 and 200 feet inside the crest of the dam. The above scheme will provide a more thorough picture of pore pressures acting within the exterior shell of the dam than that proposed for existing dams.

13.2.7.2.3 Internal Movement Devices--The installation of a device such as a slope indicator to monitor internal movements within a tailings dam or leach dump can provide valuable information regarding historical trends for a given construction method. Although the costs associated with installation and data collection are by no means insignificant, serious consideration should be given to including at least one internal measurement device for any major structure.

13.2.7.3 Maintenance Maintenance of active refuse disposal sites is performed to provide reasonable assurance that elements of a facility are functioning as intended. This is especially important where modern, cost saving design practices are used.

Access roads, necessary so that a site can be approached routinely or during an emergency, are often neglected. Roads that are difficult to pass over during good weather can be expected to be impassable during bad weather.

In the absence of vegetative slope cover, routine grading and grooming of the deposit's slopes to drain properly can prevent deep and extensive erosion, which in itself can trigger a failure. Grading equipment should be available so that regular grading can be accomplished. Often no additional equipment to perform such maintenance is required if careful and proper scheduling of work is planned. One of the simplest grading techniques that can minimize erosion on an embankment face is to grade the crest surface so that water falling or accumulating on the crest will drain away from the downstream face into the impoundment.

Drainage ditches, spillways, drain pipes, decant towers (all water conveyance facilities) need to receive regular, routine maintenance inspections and periodic maintenance cleaning to clear or prevent blockage by logs, vegetation or sliding or eroded materials.

Occasionally, in spite of routine maintenance, extensive erosion, landslides or some other unexpected situation may occur. These happenings need not be hazardous in themselves, if prompt maintenance measures are then initiated. A catastrophic failure often occurs after a series of events takes place which is initially caused by a relatively innocuous event.

Maintenance should be considered an integral part of an active or even an inactive deposit. However, abandoned sites cannot be economically maintained forever by a coal operator. Converting a coal refuse deposit to another use and conveying responsibility for any continuing maintenance should be one of the incentives for properly abandoning a refuse site.

13.2.7.4 Abandonment Perhaps the most difficult task to properly plan for in advance is abandonment. The primary reason for this is the difficulty in predicting the amount, type and rate of disposal, which can all change rapidly with changes in technology and in economic and market conditions.

Nevertheless, an abandonment scheme should be for formulated as an integral part of the refuse deposit design. The planning will save the coal industry money in several ways. It establishes long term objectives to achieve and makes abandonment a part of the overall mining system (with the advantages of systems analysis); costly modifications will not be required simply to abandon a site; and the time required for final abandonment can be greatly reduced below that which apparently otherwise may be required under legislation currently under consideration. The latter can be achieved by planning the growth of the deposit so that some abandonment procedures, such as the establishment of vegetation on slopes, can be started immediately on at least part of the deposit.

Abandonment of a dump may largely consist of grading the deposit to drain adequately, and to initiate revegetation measures for erosion control and aesthetic reasons. Many new and surprisingly inexpensive techniques to control erosion and to promote revegetation are under development. Such measures not only promote good will toward the coal operator but also can pay large returns in hazard mitigation.

Impoundments present more difficulties for planned abandonment because of the large flat surface that may be wet and inaccessible to equipment. If abandonment is nearing, the pond surface can be gradually reduced by grading from the peripheries. The pond surface should be crowned so that surface runoff water drains toward the margins of the pond area and is then carried past the pond and retaining embankment. In some cases, low permeability soil can be used on the surface to act as a sealant to reduce both combustion potential and surface infiltration of water and to provide a better material to initiate revegetation.

More attention should be given by the industry to use of the site after abandonment. In the long run, coal companies may be overlooking valuable benefits that could more than pay for land reclamation with good land-use planning. Impoundments can be developed into safe recreational reservoirs with dump surfaces graded to support shore side development. Also, some existing side-hill dumps are large enough to support recreational areas. Nearby communities may be in need of an impoundment for water supply storage or, conceivably, for a sewage treatment lagoon. Thus, in some cases, it may be safer and offer other advantages to develop a reservoir rather than to breach an impoundment. In many Appalachian states, where flat land is scarce and principally confined to flood plains, refuse deposit surfaces and strip mine benches may be excellent areas for home sites and commercial building sites.

13.2.8 Embankment Construction Inspection

Today, more than ever, construction of embankments requires a team effort. The ever-increasing escalation of costs, the need for faster scheduling and the changes occurring in the industry require full cooperation and understanding among all the parties involved. Successful production of the work under the traditional process requires the utmost order and efficiency to obtain the highest potential benefits. This goal can be reached only through the understanding that all parties have a mutual goal and are obligated to cooperate and perform to the best of their ability in order to produce a satisfactory job. This is difficult where many people of diverse backgrounds are involved from beginning to end. Successful construction requires not only proper planning and design, it also requires continuous checking, coordination, foresight, good judgment and coordinated efforts by informed and qualified individuals to accomplish the desired ends.

Inspection and control of embankment construction is necessary to assure that the structure is completed in accordance with design assumptions and requirements as set forth in the plans and specifications, and to insure that the construction costs are minimized. Effective execution of this task requires that each member of the project staff be aware of his place in the process, including his responsibilities, authority and proper line of communication.

The site inspector's responsibilities are necessarily variable in scope. The inspector must be completely familiar with the construction documents before commencement of the work. He should have a close relationship to the project designers and notify the designer of any discrepancies observed, and request clarification for all items not fully understood. The inspector must organize and maintain a system of construction records such as:

- a daily log book and daily report system,
- progress reports on a systematic basis,
- correspondence file,
- payment file,
- change order file,
- shop drawing and sample submittal file,
- substitutions file,
- test and inspection results file and
- site conference file.

The site inspector may be a full time employee of the operator if the designer and regulatory agency can be assured that he has the necessary knowledge, skill and integrity to perform the inspection duties in a professional manner. However, an inspector employed by the designer, who is highly trained and knowledgeable in the field of construction inspection, would be preferable from a technical standpoint. The assigned representative must be given enough authority to make timely decisions on the part of the operator. The operator should establish a sufficient allowance in the project budget to provide for the services of the construction inspector and/or the construction inspection staff to control construction of all structural elements of the disposal systems including the necessary dams and retaining structures (usually made of refuse material). Limited inspection is also needed to control routine dumping to assure that the planned operation is followed. Inspection will have to be full time or part time depending upon the nature of the work and how critical it is to the performance of the system when completed.

13.2.8.1 Requirements of Plans and Specifications

The person in charge of performing the work, the inspector checking the operation, as well as the operator, have the responsibility to see that plans and specifications are clear and that these documents are not misinterpreted. Therefore, a thorough study of the construction documents will be required by those performing the work and inspections prior to commencement of construction. Any errors, inconsistencies or omissions discovered must be properly dealt with prior to construction, if possible, or as soon as recognized if construction has commenced.

13.2.8.2 Verifications of Design Assumptions

Inspection and testing are possibly more important for earth structures than most other works, because of potentials for errors and deviations in actual materials properties from those assumed in the design and the potential seriousness of these deviations. By conducting inspection and testing during fill placement, it will be possible to check characteristics of the materials against those assumed in the design. If the conformance is not proper, the inspector must inform the person in charge of the construction so that timely and proper modifications can be made. If the refuse material from a particular area will not meet specification requirements, it may be necessary to seek out another source or possibly continue placing the same material under a modified design. Any design modification must be reported to and approved by the regulatory agency prior to commencement of the modified construction work.

13.2.8.3 Site Inspector's Function Proper material gradation is the utmost importance in zoned embankments impounding sludge and water. Another important aspect is to continually check material compaction by field density tests. This will serve the constructor in his efforts to attain the goal set for material strength and compression. If such testing should indicate densities below those assumed in the design, additional compactive effort, possibly under changed moisture content, or by the use of different compaction equipment, or a combination thereof, may be required. If significantly greater densities are being achieved than anticipated during design, it may be possible, under certain limited conditions, to reduce the compactive effort with a resulting savings in construction cost.

Proper recording of the construction operations and results achieved will provide a basis for evaluating the effectiveness and efficiency of the design, equipment and procedures. The analysis of these evaluations could result in design modifications, the selection of more efficient equipment or a change in procedures which could provide significant economical benefits. These economical benefits might be realized on the project under construction and they may also be applicable to similar jobs in the future.

The importance of a competent construction inspector cannot be overemphasized. Good inspection can be worth many times its cost in preventing errors and omissions of construction that might impair the safety and durability of the project and interfere with obtaining value for the money invested. Good inspection demands the results needed but also relieves any unnecessary requirement or impediment to the program that can be eliminated without adverse results to the program. This means that improved procedures can be used if they produce results compatible with the design requirements and specifications.

The construction inspector's basic function is to assure that the most reasonable compliance possible with the construction specifications is achieved, consistent with the design objectives. In addition, he serves as an extra pair of eyes and should not be satisfied with merely reporting mistakes in the work after they are made. He can avoid misunderstandings by continually reviewing the construction documents and working in conjunction with the person in charge of construction. He should look ahead and be fully acquainted with the construction documents and all phases of the work. He can thus help avoid costly and time-wasting mistakes and foresee bottlenecks due to delayed delivery of material or improper scheduling of the work. By promptly inspecting delivered materials and observing the preparation and installation, he can prevent costly tearout, replacement or redoing of the work. In these and other ways, he can perform a real service to the operator and designer. He thus becomes an important member of the team needed to ensure a smooth-running construction process and a safe and properly constructed project.

The construction inspector must be continually alert to any condition that could impair the safety or functioning of the completed project: modifications to existing structures, as well as construction of new projects, may create temporarily oversteepened slopes, may loosen temporary fills, may block streams, etc., and should therefore be carefully observed and their potential for creating a hazard judged.

Note, however, that the site inspector is not responsible for and should not, in most instances, undertake responsibilities that are not a part of his services; for example:

- Telling the constructor how to construct the work.
- Guaranteeing that the work is constructed in strict compliance with the contract documents. (This is the responsibility of the constructor.)
- Interpreting or ruling on the intent of the construction documents.
- Accepting the work or portions of it. The designer is responsible for recommending this to the operator.
- Methods of operating equipment, including safety. This is the constructor's and health and safety regulatory agency's responsibility.

13.2.8.4 Regulatory Agency The regulatory agency should receive and review a complete set of plans and specifications, including corrections and amendments thereto. These should be evaluated from the standpoint of adequacy, completeness, construction safety and potential for creation of future hazards. The approval of the plans will be based on such review. Approval of the plans and specifications for construction does not imply that the completed project will not be disapproved if construction is not performed in accordance with the plans and specifications.

The regulatory agency should have its inspection staff regularly check the construction operations. As a minimum, the site should be visited when foundations are exposed and prepared for placement of materials whenever a new operation commences, and at regular intervals. During these visits, inspectors should cover the entire site, paying particular attention to the following:

- foundation conditions and preparation,
- unusual site conditions not anticipated in the design,
- construction procedures,
- methods of on-site inspection and control,
- test frequencies, methods and results,
- any hazardous conditions and
- rate of progress.

A complete written record should be made of each inspection and photographs should be taken of critical items, as well as general site pictures and operations. If any deficiencies are observed, they must be recorded and reported to the operator's representative. It is the operator's responsibility to devise a method of correcting the deficiency. The regulatory agency must make certain the deficiencies are corrected, but they cannot infringe upon the operator's authority by dictating the method of correction.

The methods of inspection and testing to be applied during construction will depend to a considerable extent on the provisions of the specifications. The inspection techniques will be dictated by the type of specifications--method specifications or performance specifications.

In Method Specifications, as they are defined herein, the method of construction is outlined so that the constructor may produce the finished product for the required services throughout the desired period of time. It therefore becomes necessary to observe construction to ensure that the specified method is followed and periodically test the placed materials as the work progresses. Obviously, method specifications impose greater burden on the designer; the product can only be as good as that resulting from the specified method of construction. If an inadequate product results, revised construction techniques or design revisions will have to be made, as an adequate product must be produced.

On the other hand, Performance Specifications allow the constructor to carry out the construction work as he chooses. However, he must arrive at the required product. The adequacy of the product can be measured by tests, as noted under Testing in the following section, similar to those performed under conditions of method specifications.

13.2.8.4.1 If method specifications are used--

- Operations--As the specifications outline the thickness of material lifts, the number of passes to be applied to each lift and the type of compaction equipment to be used for compaction, the inspector will have to check that the constructor complies with these specifications. Furthermore, the constructor must use the specified material type and place material at the specified moisture content.

  The latter may be difficult to comply with due to weather conditions. Also, the available materials may be somewhat different from those anticipated. For these reasons, specifically, modifications in the plans and specifications may be required to obtain the desired end product. The inspector should also assure that the constructor complies with plans and specifications as they relate to zoning in an impoundment facility, the required final grades and the like.

- Testing--The primary tools for evaluating the degree of compaction are earthwork control tests. These are usually conducted in the laboratory and define the maximum dry density and optimum moisture content for the various laboratory compaction methods. The optimum moisture content is the amount of moisture which gives the maximum density for a given compactive effort, or that which requires the least compactive effort to achieve the highest degree of compaction.

The test results will assist the inspector or technicians, as well as the constructor, in moisture conditioning during construction so that the minimum compactive effort will suffice to achieve the required compaction. In addition, the control tests will serve the purpose of evaluating whether the required fill compaction is met. This in turn will indicate whether the required strength of the placed material is as specified.

Gradation tests to check actual drainage characteristics of the materials used are also required during construction. Some fine-grained soils must have specific plasticity characteristics. Atterberg Limits testing is generally performed as a check to confirm these characteristics.

13.2.8.4.2 If performance specifications are used--

- Observations--As the constructor in this case will not be guided as to how to perform the work, but rather will have to guarantee that the product is in compliance with requirements, he may exercise his own judgment with respect to construction procedures. The inspection procedure will take a somewhat different form in comparison to that required when method specifications are used. Checking of lift thickness of the material placed and the number of passes over each lift with the compaction equipment will not be required. The inspector will, however, be required to observe to see that the general construction procedure is adequate and that improper materials are not placed.

  Extensive testing will, in this case, be required to evaluate the consistency of the product with plans and specifications. The tests will indicate whether or not the product may perform as anticipated and serve the intended purpose. If negative results are indicated, removal of the placed materials and replacement with adequate materials will be required if material gradations are improper, or the material would need reworking if, for example, moisture conditioning is improper or compacted densities are inadequate.

If the constructor consistently cannot produce the required product by the construction procedure he follows or other methods he may try, the designer may be forced to modify the specifications to a method specification. However, this should be avoided, if at all possible. It will be preferable that the constructor modify his construction procedure so that the required product can be produced.

- Testing--Testing procedure should be similar to those outlined above. The number of tests would most likely have to be greater. Hence, a greater number of technicians should be anticipated in comparison to those required when method specifications are used.

13.2.8.5

It is always necessary to provide written correspondence among the parties to fulfill the requirements of the specification documents and/or regulatory agency requirements. In addition, the orderly construction of the work requires distribution of information to many sources, and this is best done in writing.

Correspondence is achieved through the use of letters, memoranda, forms, reports, graphs, electronic devices, etc. It is recommended that adequate documentation be developed during the construction phase as a good practice by all the parties. Many types of forms have been developed, and it can be said that there is a form for any need. Many organizations, individually or through collaboration with other organizations, have developed forms in an effort to standardize, but complete unanimity as to type, contents, arrangement, etc., is not always achieved.

On the proper forms, the inspector, having assured proper compliance with plans and specifications, should provide confirmation to the interested parties. The reports should contain a summary of the construction procedure followed and the results of all field and laboratory tests. These reports should be submitted on a regular schedule to the regulatory agency.

The construction procedure and test results should be reviewed with the design organization during construction. This may be advantageous from the standpoint of initiating timely and beneficial construction revisions to possibly obtain the required result for less cost.

13.2.9 Embankment and Impoundment Recognition Summary

While it is true that many coal refuse dumps and impoundments have been standing for considerable periods of time, this should not be taken as any guarantee that a given dump or impoundment is not unstable today. A slope of an embankment may remain relatively undisturbed for many years even though it is in a metastable condition; that is, the factor of safety is only slightly greater than one. Any change in the condition of the slope or its material constituents can cause a concomitant change in its stability. Figure 13-23 indicates the four basic elements of interest in recognizing how changes in slope properties can create stability hazards.

More detailed discussions of stability are available elsewhere in this report, and in referenced literature. The purpose of this section is to present a basic summary of hazard causes and their recognition.

13.2.9.1 Conditions Affecting Stability From the basic stability diagram (Figure 13-23), it can be seen that any change in conditions in any one of the four areas will affect the overall stability characteristics of the embankment.

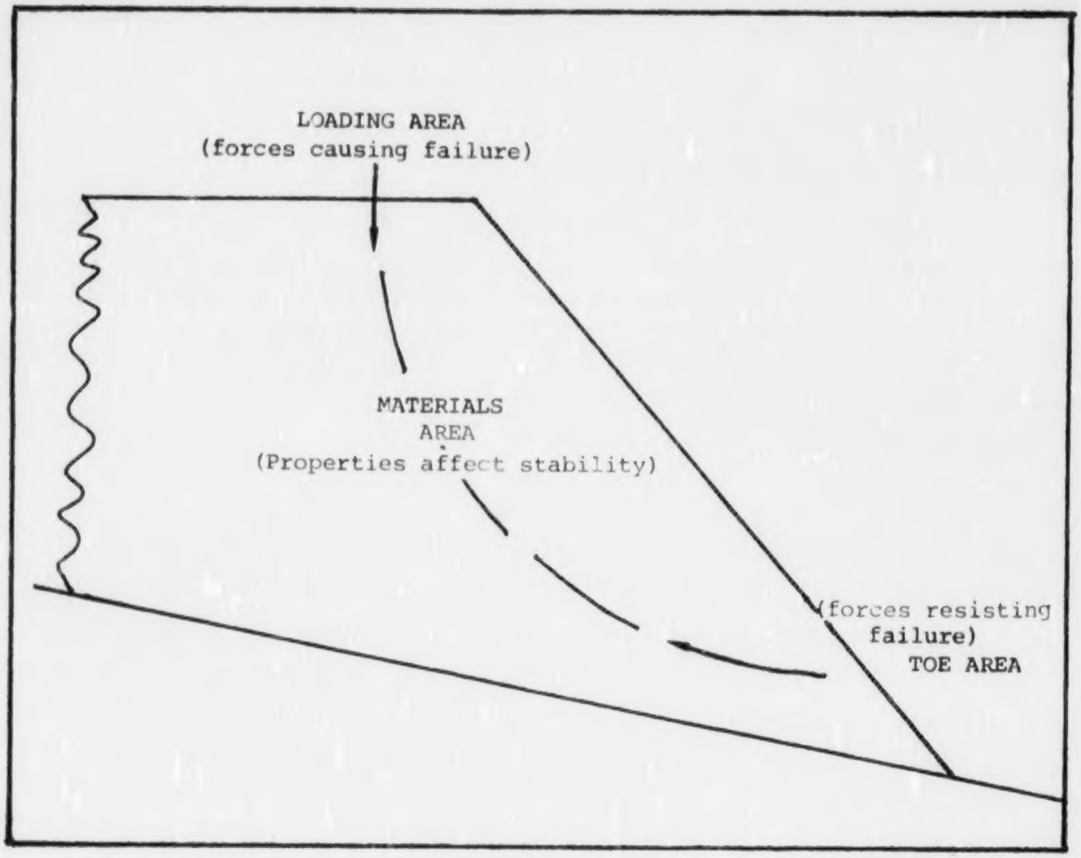


Figure 13-23

Basic Stability and Hazard Diagram

13.2.9.1.1 Loading area Additional loading can be due to additional materials placed on the crest for disposal, by heavy vehicles running on or near the crest, or by the introduction of water due to seepage from ponding on the upper surface of the embankment.

13.2.9.1.2 Toe area Removal of the material at the toe, as is often done in excavating red dog products for domestic and industrial use, can decrease the forces resisting movement. Any other changes in the toe area caused by erosion of the surface, or by wave action from a pond created immediately downstream, will also affect this area. The practice of placing final clarification ponds at the toes of coal refuse embankments (a fairly common practice) is especially to be discouraged.

Excavation into the natural ground material in the immediate vicinity of an embankment can also have resultant effects, regardless of the purpose of the excavation.

13.2.9.1.3 Materials area Steepening of the slope can be caused by red dog excavations, by road construction on the face of the embankment or by surface erosion caused by uncontrolled drainage on the slope face. In the case of overtopping of an embankment, rapid erosion can take place with resultant slope steepening.

Burning of the carbonaceous material in a coal refuse dump or inpoundment can cause a reduction in volume and/or the density. This may lead to cracking of the embankment and the opening of seepage paths in to the materials area. Explosions within burning banks have occurred upon the introduction of water. However, all of the results of burning are not adverse, since the shear strength of the material may be ultimately increased and, where sufficiently high temperatures occur, fusing of siliceous materials may take place.

If sudden vibratory stresses are applied to the materials in a relatively loose state, particularly if they are saturated, a reduction in the effective stress between the particles can take place, thus reducing the shear strength. These vibratory stresses may result from blasting, equipment operating on the dump, mining subsidence, impact of dumped or sliding material and finally from seismic shocks. In extreme cases, liquefaction of the material can result from this type of embankment loading, with resultant disastrous failures.

13.2.9.1.4 Foundation area Any increase in the water level (the phreatic surface) within the foundation or within the materials area can produce a reduction in effective shear strength. This increase in water level, or pore pressure, can be caused by surface water entering the material, seepage water from the pond behind the embankment, blockage of diversion culverts under or within the embankment or the construction of an embankment over an area with natural springs. Other factors might include changes in permeability due to subsidence in the area, filter materials becoming inoperative or ineffective due to clogging and chemical or weathering changes of the dump materials. Finally, in extreme temperature zones, freezing of the downstream face may cause buildup of seepage water because of the reduction in the permeability of the exit area.

Piping, wherein material is removed by internal erosion due to large quantities of water moving through the foundation of the embankment, can form voids and affect stability. Cracks due to burning, dump settlement or areal subsidence can lead to piping failures, as can the collapse of pipes or culverts within the embankment or under the foundation area.

Rapid drawdown of the liquid retained behind an embankment can cause abrupt changes in the seepage forces involved in the upstream slope. Slopes aginst which water has been retained for a considerable period will have usually achieved seepage equilibrium and are more susceptible to drawdown distress. Drawdown problems are directly in proportion to the length of time the water has been impounded and to the rate of drawdown, and inversely proportional to the permeability of the slope materials.

13.2.9.2 Forms of Instability Signs of distress or instability in an embankment are usually related to the factors discussed in this chapter. Many of the signs have unique visible characteristics which can aid in reducing the cause of the distress.

13.2.9.2.1 Rotational slips Movement of material under unstable conditions within a dump or impoundment frequently will be an approximate cylindrical or spherical surface. Other movements may take noncircular forms such as wedges, depending upon many factors including shear strength, cohesive and frictional components, foundation characteristics and stratification of the dumped material.

Rotational slipping usually exhibits tension cracks at the top of the slope, accompnied by slumping or bulging of the material near the toe of the slope. If the foundation material is soil, the bulging may take place in the natural ground beyond the toe. Rotational slips develop at variable rates, and the signs may be visible for only a short period of time before failure, or they may be discernible over long, slow periods of deterioration.

13.2.9.2.2 Surface slips When dumps are constructed with little or no compaction and the slope material is essentially at the angle of repose, as is the case with aerial tram dumping without additional equipment utilization, sliding of shallow surface layers may take place in a manner resembling sheet flow.

13.2.9.2.3 Flow-type slides Some granular refuse materials may be dumped in a manner that results in a material which will permit rearrangement of the granular mass into a more dense state under stress conditions. If the material is saturated, the attempt to achieve the more dense mass may be inhibited by the inability of the water to escape from the mass rapidly enough, resulting in the temporary suspension of the material in the water (excess pore water pressure). The result is an unstable mass resembling a viscous liquid which will move as a flow slide.

A rapidly moving stream of water and water-borne particles may result from intense surface runoff on a slope, or from large piping volumes of water exiting the mass. The suspension of solids will have a consistency near that of a heavy mud, and the flows are termed mud flows.

13.2.9.2.4 Creep When the materials that form an embankment move at a slow, steady rate down and parallel to the existing slope, the failure is known as creep. Since the rate of movement of all the materials on the slope may not be the same, the slide surface usually will not remain parallel, but will either form waves parallel to the crest length (when the upper portion moves faster than the lower portion), or create tension cracks parallel to and near the crest (when the lower portion moves faster than the upper portion). When a slope is in a metastable condition, a single action, such as cutting an access road on or near the downstream toe of an embankment, may initiate a creep failure. Should the failure accelerate, either a flow-type or deep-seated slide may develop.

13.2.9.2.5 Back-sapping When the flow of water on the downstream face of an embankment is intermittent, either due to piping or surface runoff, a concentrated area of erosion may be produced which continues to progress up the slope. Each subsequent movement of material will be of increasingly greater areal extent, and the resulting physical evidence is termed back-sapping. Excavation of slope material on a continuing basis, again red dog mining is a good example, can result in this type of slope movement.

13.2.9.3 Factors Affecting Stability There are many factors that can and will affect the stability of an embankment. The majority of these factors are involved with water in its various roles, embankment size (height and other dimensions) and movement. A list of most of the factors that affect embankment stability follows, and must be included in any general data form being utilized for coal refuse disposal evaluations:

- size (height, width, volume),
- slope steepness,
- slumping, sloughing, sliding--is is surficial or deep-seated?
- cracks--are they parallel to embankment crest or to the stream direction?
- burning,
- seepage--location, volume, is it carrying solids?
- heavy downstream stream flow in dry weather,
- elevation of free pond water with respect to embankment features,
- sink holes in impounded sludge surface,
- boils in downstream toe area,
- bank erosion,
- embankment vegetation,
- methods and location of current refuse disposal,

- abutment conditions--can a slide above the embankment endanger it?
- reservoir and watershed--can a slide (a seiche) into the reservoir cause overtopping?
- vegetation in the watershed,
- has mining taken place beneath the area--embankment, reservoir, etc.

These factors may be considered the most important ones affecting visible signs of instability. However, they are not the only factors of which one must be aware. The following pertain to important factors concerned with more specific areas such as appearance of the site, embankment characteristics, sludge disposal procedures and water, both as they relate to the embankment and to possible flooding.

13.2.9.3.1 Appearance of the Site In general, it has been found that the better the physical appearance of the site and the disposal operation, the safer will be the facility. However, like most generalities, this is not always true, and one must be able to distinguish between cosmetic and real safety practices. For example:

- Is the vegetation cleared from the pond and embankment areas?
- Is the disposal of the cleared material properly controlled?
- Is rubbish other than coal refuse being randomly discarded?
- Is the embankment burning?
- Is the materials handling equipment in good condition?
- Is the embankment graded? Groomed? Revegetated?

13.2.9.3.2 General Embankment Characteristics The following items describing the characteristics of the embankment should be noted by a competent inspector:

- Is the embankment active, inactive or abandoned?
- Is the embankment being enlarged? At what rate? How? Where?
- Is the material fine or coarse? Does the material weather from coarse to fine?
- Is the material being compacted? How? To what degree?
- How high is the embankment? What is the planned final height?
- How wide is the embankment? What is the top (crest) width? What is the base width? What are the slopes?
- Is the embankment being raised by the upstream method? The downstream method? Another method?
- Is the embankment burning? Could the introduction of water cause an explosion? How much has burned? What percent is red dog?
- Is rubbish or other combustibles being deposited with the refuse?
- Are there cracks in the embankment? Where? Direction of cracking?
- Have there been slides on the surface? What type? What extent?
- Does the embankment retain water? Fine sludge? Is there a pond now?
- Is there a diversion pipe in or beneath the embankment? Is the pipe clear or obstructed? Can the water level be fully controlled?
- Is there seepage present? Where? What volume? Any coloration? Any solids being transported? Does seepage pond on the slope?

- What is the embankment foundation? Was it stripped or grubbed? Was a key trench or any other barrier included in the foundation?

13.2.9.3.3 Sludge Disposal Considerations The following items describing the characteristics of the embankment should be noted by a competent inspector:

- At what rate is sludge being deposited? Continuously? Intermittently? Are there periods when the pond dries out?
- Where is the sludge being deposited? Upstream or near embankment? Does the sludge deposition erode the embankment?
- What is the relationship between sludge, water and available storage? How fast is available storage being filled? Is there adequate freeboard?
- Is there evidence of piping in seepage water? Are there boils on the face of the embankment? Are there sink holes on the sludge surface?

13.2.9.3.4 Water as it Relates to Embankment Stability Many, if not most, of the signs that indicate embankment distress are associated in some way with either subsurface or surface water in relation to the retaining embankment.

- The less the difference in elevation between any seepage water on the downstream face and the water level in the pond, the greater the cause for concern. Try to relate how the embankment has been constructed with the location of any seepage and visualize the phreatic line. Remember that water emerging on the downstream face may not be free, that is, no apparent surface flow may be taking place.
- On the downstream face are there:
    - Gross changes in color in a zone or on an approximately horizontal line?
    - Vegetation differences in color or amount in this zone or on this line?

    - Variations in surface erosion? (Often erosion is more pronounced below the zone of saturation.)
    - Minor surface slides below the zone of saturation?
- If there is free water visible on the downstream face:
    - Identify the point or points where the water exits.
    - Estimate the quantity, temperature, quality and clarity.
    - If the solids are being carried, estimate the quantity and source.
    - Determine if the seepage flows are causing erosion of the face.
    - Does the seepage flow pass beyond or is it ponded on the surface?
    - Try to relate present or past seepage areas to corresponding pond levels.

13.2.9.3.5 Water as it Relates to Flooding Since a major rain storm and the resultant high storm runoff might substantially increase any hazard associated with the impoundment, the following factors should be determined:

- How is the possible storage volume available?
- How much of the possible storage volume is filled with sludge?
- How much of the possible storage volume is filled with water?
- What is the size of the watershed behind the impoundment? Determine the runoff characteristics of the watershed such as amount of vegetation, infiltration potential, etc.
- Have any provisions been made to carry runoff around the impoundment? Are there diversion ditches? Are they functional and maintained?

Would they be blocked by slides during high runoff?

- Is there a spillway? How was it constructed: Open cut? Pipe? What is the relationship of the spillway size to the estimated storm runoff? Does the spillway discharge pass over the embankment so as to erode the downstream slope?
- How would a rise in the pond water level affect the phreatic surface in the embankment? What effect would such a rise have on the embankment stability?

13.2.9.4 Hazards Rating System When what appears to be a potentially disastrous condition at a refuse disposal site is identified or suspected, an Emergency Hazard Rating System is useful on which to base a degree of reaction and to facilitate communication. The setting of a numerical hazard rating on a site under study, while desirable from an administrative and field inspector's point of view, is a difficult, if not impossible, procedure. Since a single deficiency can be the cause for a site to require immediate review or action, a combination of minor deficiencies from several rating elements does not necessarily best indicate that a site is safe or unsafe.

A simple direct system is best for this purpose, and an Emergency Hazard Rating System based along the following lines can be utilized:

I. High Potential for Loss of Life

II. High Potential for Loss of Property

III. Low Potential for Loss of Life or Property

IV. No Potential for Loss of Life or Property

It is also desirable to have a rating system for less immediate situations. In this context, a more complex system can be developed. For example, an evaluation system can be established based on the physical conditions of the deposit and the consequences of failure. The condition rating can be obtained from the results of the inspector's observations and data from the Basic Data Forms (see Appendix A), such as size, storage volume, etc. The consequences of failure ratings can be assessed from the determination of the characteristics of the area that could be affected by a failure. Table 13-4 outlines one possible approach.

Table 13-4

Possible Consequences of Embankment Failure

Consequences of Failure	Condition
I. High potential for loss of life and property	A. Major Deficiencies--Impoundment
II. High potential for loss of property	B. Major Deficiencies--Dump
III. Low potential for loss	C. Minor Deficiencies
IV. No potential for loss	D. No deficiencies

The priority for review can be determined by combining the relative importance of each of the two categories shown in Table 13-4 and placing the combined ratings in descending order of importance as follows:

1. IA High potential for loss of life and property; Major Deficiencies--Impoundment
2. IB High potential for loss of life and property; Major Deficiencies--Dump
3. IIA High potential for loss of property; Major Deficiencies--Impoundment

4. IIB High potential for loss of property; Major Deficiencies--Dump
5. IC High potential for loss of life and property; Minor Deficiencies
6. IIIA Low potential for loss; Major Deficiencies--Impoundment
7. IIC High potential for loss of property; Minor Deficiencies
8. IIIB Low potential for loss; Major Deficiencies--Dump
9. ID High potential for loss of life and property; No Deficiencies
10. IIIC Low potential for loss; Major Deficiencies
11. IVA No potential for loss; Major Deficiencies--Impoundment
12. IID High potential for loss of property; No Deficiencies
13. IVB No potential for loss; Major Deficiencies--Dump
14. IIID Low potential for loss; No Deficiencies
15. IVC No potential for loss; Minor Deficiencies
16. IVD No potential for loss; No Deficiencies

These ratings, and the basis for them, are not intended to be stringent or constraining. They cannot be, due to the nonspecific nature of the contents of the evaluation. They are only intended as a preliminary method upon which an order of priority for review of refuse deposits can be based. A certain degree of flexibility must be allowed because of the many variables involved.

13.2.10 Control of Mine Drainage from Coal Refuse Deposits

As documented in EPA publication EPA-R2-73-230, Control of Mine Drainage from Coal Mine Mineral Wastes, Z. V. Kosowski, 1973, with proper planning and diligent attention to basic details, relatively basic and simple technology can be applied to the stabilization of most coal mine mineral waste deposits with the subsequent control of pollution and with a minimal impact on the environment. Recognizing that the indicated report was based on what was accomplished at one site, in one location under a given set of conditions and that it should not be construed as applicable to every individual situation, the following conclusions may be applied as axioms:

1. Acid runoff from refuse piles can be controlled by covering the mineral wastes with soil, establishing a vegetative cover and providing adequate drainage to minimize erosion.

2. No significant differences were observed in acid formation rates from the three individual test plots covered with a nominal 1 foot, 2 feet or 3 feet of soil. However, it was more difficult to uniformly place 1 foot of soil on the steeper slopes.

3. Slurry lagoons containing the fine coal rejects can be stabilized and the air pollution problem controlled by either a vegetative cover established directly on the mineral wastes without soil or by the application of a chemical stabilizer. Chemical stabilization is only a temporary measure, and vegetative covers should be the permanent solution to slurry lagoons.

The primary ojective of the demonstration project conducted in cooperation with the Midwestern Division of Consolidation Coal Company was to establish water and air pollution abatement techniques which would provide an essentially permanent stabilization, would require a minimum of maintenance and be aesthetically pleasing. The basic principle adopted consisted of sealing the coal refuse with a suitable cover to minimize the movement of water and air into the refuse, thereby reducing or eliminating the subsequent formation of acid, siltation, erosion or fugitive aerosol emissions.

During the course of the project, the primary attention was directed towards the vegetative covers that could be established and maintained with conventional agriculture techniques and machinery. Since the surface of the refuse disposal site was highly acidic (pH < 3) and could not by itself support a vegetative cover, a suitable thickness of clean earth was placed on the graded refuse pile and a vegetative cover established thereon.

The mechanism of control originally postualted was as follows:

1. The cover should be sufficiently impermeable to decrease or stop water movement into the pile. When this occurs, the products of oxidized pyrite will not be washed away during periods of rainfall, and fresh pyrite surfaces will not be exposed. Further, a vegetative cover can function as a water-consuming layer through the principles of evapotranspiration, thus further reducing the quantity of water entering the interior of the pile.

2. The cover should be sufficiently impermeable to oxygen to act as an efficient diffusion barrier. Since oxygen (and water) must be continuously present to support the pyrite oxidation reaction, any material effectively separating the pyrite from the atmosphere will cause the oxidation reaction to either slow down or cease completely. The characteristics of the cover then control the oxidation reaction. In addition, the cover can function as an oxygen-consuming layer. A vegetative cover such as grass may build up enough organic matter in the soil to support high rates of aerobic bacterial activity. Such a

layer can be effective in removing oxygen from the soil atmosphere before it reaches the zone of pyrite oxidation.

3. The above phenomena, either singly or in combination, should reduce the acid formation over a period of time to negligible quantities.

The question of soil thickness in covering refuse piles appears to be a controversial one. From a technical standpoint, it is difficult to justify topsoil cover greater than one foot thickness on a properly graded refuse pile with adequate drainage control. Anything greater than one foot can be regarded as safety factor to camouflage improper grading and inadequate drainage. Of course, as the graded slope increases beyond the aforementioned, the difficulty of applying a nominal one foot of soil cover increases correspondingly.

When clean earth is to be used to cover a refuse pile as a prelude to establishing a permanent vegetative cover, a sufficient number of soil samples should be taken from the borrow area and analyzed for soil nutrients. If a substantial depth of soil is to be moved from the borrow area, core samples to the ultimate depth of the borrow area should be taken and analyzed. Submitting samples from surface scrapings can lead to erroneous results, since rarely will the soil from the surface of a borrow area find its way on the surface of the covered refuse pile. The areas to be seeded should be divided into smaller segments that can be limed, fertilized, seeded and mulched promptly (e.g., within one or two days) after the earth cover has been applied. Otherwise heavy rains inevitably occur that lead to erosion and gulleys and the necessity of redoing what has already been done. Regarding specifics of fertilizers, lime requirements and seed mixtures for grass covers, it is almost impossible to recommend any specifics because soils, climatology and ultimate land use vary so widely. Drainage and pH control of the soil are basic to the establishment of most vegetative covers. Native grasses with a good past performance record should be favored. Fertilizer application should be made on the basis of the grass seed selected. It is good practice to include in the grass seed mixture at least one species of native legumes. A complete and comprehensive listing of grass seed mixtures with recommended fertilizer requirements and other valuable information is available in the Department of Agriculture "Grass, The Yearbook of Agriculture, 1948", available from the Superintendent of Documents. Additionally, the benefits of surface treatment with an alkali such as limestone, lime, fly ash or waste alkaline products (prior to covering with earth) have not been adequately demonstrated. It is recognized that even if effectively sealed, most refuse deposits would continue to generate acid for several years. It is therefore paramount that after sealing and during establishment of the vegetative cover, the most important parameter, i.e., the one given the next highest priority, is erosion and drainage control. Everything else should be considered as being secondary. Uncontrolled runoff damages everything. Reducing the velocity and controlling the flow of runoff can make the greatest single contribution in ultimately abating pollution from refuse piles. A variety of measures are available to control runoff. These include proper grading, subsurface drains, diversion ditches, terraces and vegetative covers.

It is not possible to lay down any hard and fast rules as to a specific slope for the grading operations, as every situation is different. Slopes greater than 1:2 are more difficult (but not impossible) to construct and maintain with conventional earth-moving equipment.

Techniques developed in the interstate highway program and in major construction projects can be directly applicable to refuse pile grading. Equipment such as graders, tractors, bulldozers and earth-carrying vehicles is readily available, and improvements in capacity, reliability and efficiency are continuously being made by the manufacturers. When the slopes exceed the capability of conventional earth-moving equipment, a variety of other equipment is available such as draglines and shovels and, under extreme conditions, manual labor. Bench terracing is another practical alternative that may be adopted for extremely steep and/or long slopes. The top of the pile should be formed into a dished plateau or bowl. All peaks and ridges should be graded toward the low point in the bowl since this helps to reduce the amount of runoff and surface water draining along the sides of the pile with a corresponding reduction of erosion and gullying. Adequate drainage from the bottom of the dished area is a must and can best be accomplished by open ditches made and maintained out of a variety of inexpensive materials--wood troughs, concrete-lined channels or large-diameter metal or plastic pipe cut lengthwise and firmly anchored into the ground. Grass sod should not be overlooked as an effective alternative. The total cost of grass sod may not be as high as other alternatives. The collection and treatment of the drainage will be addressed in Section 13.2.12, Preparation Plant Process Water. Slurry lagoons, because of their unique physical and chemical characteristics, should be treated differently. Grading is usually neither required nor desired. However, drainage control is extremely important because of the unstable nature of the slurry material. Adequate drainage facilities and erosion control should be provided to reduce the velocity and control the flow of runoff. Where gulleys already exist, these can be filled with bales of straw, slurry, clean earth or other inert fill. When a permanent vegetative cover is planned, careful attention to opening the dikes at strategic points must be provided since most slurry lagoons are completely enclosed during active operations. This will require the construction and maintenance of permanent, stable structures at the outlet of the lagoons to control the runoff and direct it into the nearest stream. Otherwise, channeling and gullying will take place and slurry will be deposited in the nearest stream.

The establishment of a permanent grass cover directly on the slurry lagoons, without the use of topsoil, is a relatively simple procedure provided a vehicle is obtained that will traverse the lagoons with a load. The procedure consists of soil testing, limestone application, fertilizer addition, grass seed sowing and mulching with straw. For purposes of establishing grass covers, slurry lagoons can be classified as free-draining, very poor-grade soils. Drought-resistant species and legumes native to the area should be considered for use in any grass seed mixture for slurry lagoons. Straw is the preferred mulch for both the refuse pile and the slurry lagoons since the soils are essentially barren of any humus. Chemical stabilization of slurry lagoons is only a temporary measure because of solubility, abradability and nonrenewable nature of the chemical agent. Because chemical stabilization does provide almost instantaneous stabilization and dust suppression, it does present an attractive temporary option. However, permanent vegetative covers should be the ultimate solution for slurry lagoons.

13.2.11 Closed Water Circuit

The possibility that regulations will be developed stating that for "coal preparation plants, zero discharge systems will be required" have forced the coal industry to actively pursue 100% closed water circuits. The current need for more and cleaner energy is in direct conflict with the goal to completely close the preparation plant water circuit. To produce a higher quality product (less sulfur and ash at a respectable Btu recovery), the coal must be crushed finer and finer to liberate the entrained impurities. The smaller the coal particles become, the more complicated the coal washing process becomes. The direct result is that much greater washing capacities must be incorporated into the preparation plant which in turn means an increase in the use of water.

For a typical 1200 ton per hour plant, a waste water treatment facility that can handle approximately 800 gpm of slurry containing as much as 75 tph of solids with 75% of the particles being 200 mesh or finer and with an ash content in excess of 50% must be available. The problem in closing a water system of this magnitude is how to treat the waste material effectively and economically to produce a product that is 100% acceptable in terms of water effluent standards while at the same time creating a handleable solids material.

The techniques of dewatering and drying of the clean coal and refuse products has been addressed in detail in Chapter 8; however, the final water clarification problems begin as the water effluent from the dewatering and drying process leave the actual process flow. The dilemma in closing a plant water circuit begins with the thickener design. Depending upon size consist and ash content, the engineer has to choose the type of thickener that not only provides low initial capital investment but also a low operating cost. The final decision of what type to install is usually dictated by the projected thickener feed size consist and quantity of waste water to be processed.

13.2.11.1 Thickeners and/or Clarifiers Thickeners are usually circular tanks, 40 to 200 feet in diameter. The slurry is introduced into the thickener at the center. The clarified overflow is removed at the outside edge of the top rim of the tank. As the slurry flows from the center to the rim, the solids settle to the bottom of the tank, where they are scraped to the center of the tank by plows. In one type, there is a slowly revolving vertical shaft in the center of the tank with a number of radial arms attached to the shaft, parallel to and a short distance above the tank bottom with vertical plates (plows) set obliquely to the arm and attached to the bottom of the arm. The plows direct the settled solids to the center of the tank where they are removed as tank underflow. Any degree of removal of solids which can be settled can be attained in a thickener by the proper correlation of capacity and dimensions. Figure 13-24 shows a steel tank flat bottom thickener and a concrete tank sloping bottom thickener.

Most thickeners are installed with some type of arm lifting device, particularly in applications involving flotation tailings. The fine clays may occasionally tend to gel, which retards the flow to the withdrawal point causing a ring or "donut" formation. If the arms can be raised and lowered, the ring can usually be broken up. Also, there is always the possibility of coarse coal entering the thickener due to flotation cell malfunction or to a screen break. A lifting device may permit continuous operation without excessive torque on the mechanism by lifting out of the coarse settled solids and lowering the rakes as these solids are removed.

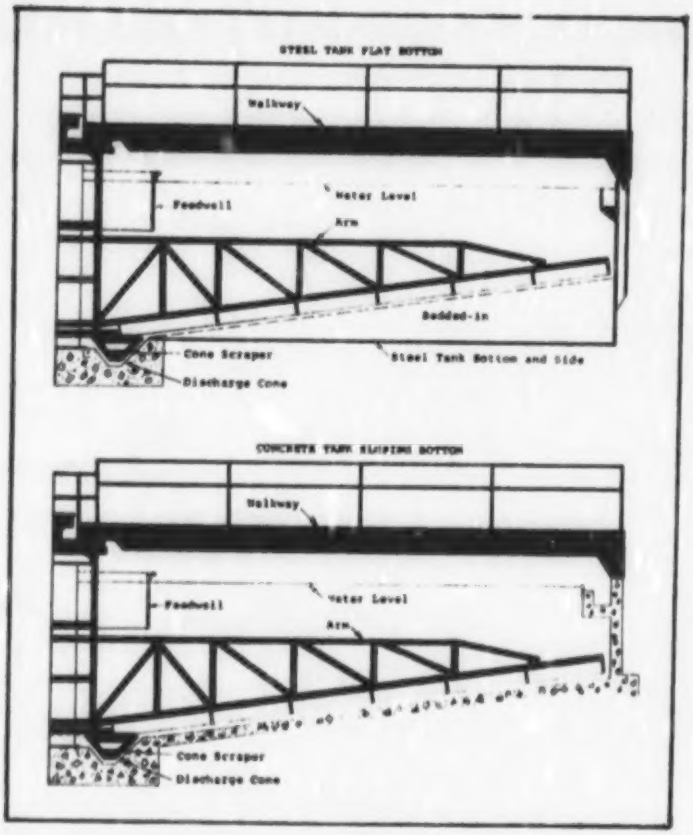


Figure 13-24
Thickener Tank Designs

Feedwells in the tank center are designed to quiet the incoming flow prior to entry into the tank proper. There are many designs and modifications which dissipate the high inlet velocity head by imparting a high degree of small eddy formation and, preferably, a radially uniform distribution of flow into the tank. A poorly designed feedwell will result in jets or streaming beneath the feedwell skirt which can create undue turbulence in the thickener resulting in an overflow containing unsettled solids.

Pumping systems for withdrawing the underflow have typically been installed by means of a tunnel system beneath the thickener. The pump may be located at the center of the thickener in an enlarged section of the tunnel, or the pump suction piping may lead through the tunnel to a pump house adjacent to the tank. Figure 13-25 depicts the standard Tunnel System.

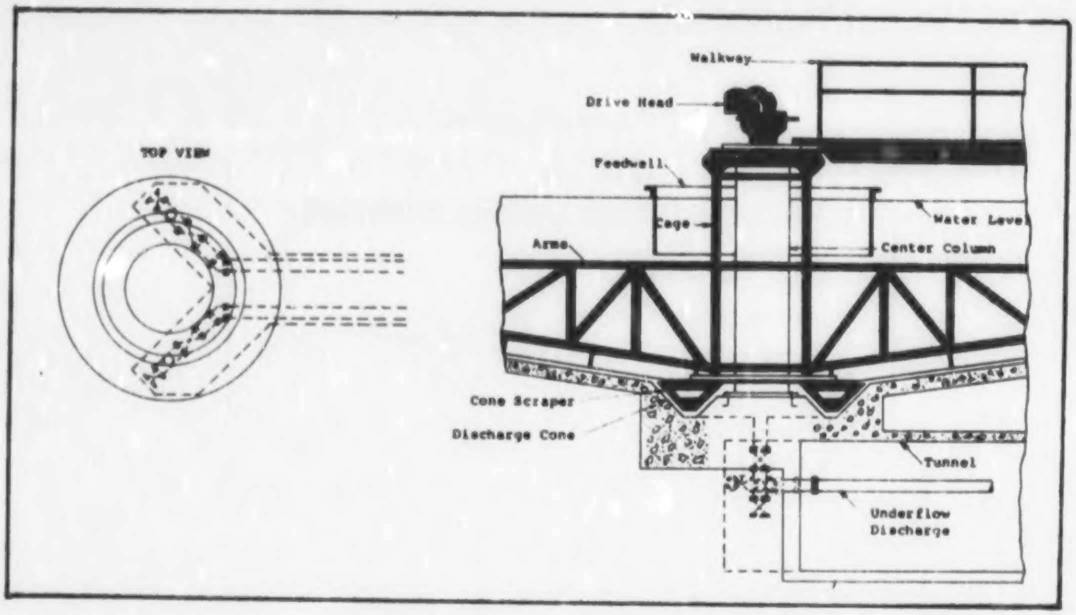


Figure 13-25

Standard Tunnel Solids Withdrawl System

To accelerate the settling of the solids, chemicals for flocculation are usually added. Many types of chemicals are used including inorganic types, such as alum, lime, iron salt and sulfuric acid and organic types such as pre-gelatinized starch and synthetic organic polymers.

Another form of separating equipment is the Drag Tank, which is a relatively long horizontal tank of rectangular or trapezoidal cross-section, with one end inclined. The suspension of solids in water is fed in at the end opposite the inclined end and the overflow is removed from the top near the latter end. As the water flows through the tank, some of the solids settle to the bottom. A flight conveyor is provided for the removal of the settled solids. The path of the conveyor is along the horizontal bottom, up the inclined end, returning over the top and vertically downward and finally turning and connecting with the horizontal portion. Dewatering takes place after the conveyor leaves the water and passes up the incline. The amount of dewatering depends on the length of the incline and the conveyor speed. The conveyor speed should be approximately the horizontal velocity of the suspension through the tank.

In passing through a Drag Tank the solids in a feed suspension settle by an amount which depends upon the time available for settling and the terminal velocity of the solids. The time for settling is a function of the cross-sectional area of the tank, the volume flowing and the distance between the inlet and overflow.

The EIS clarifier, a high capacity sedimentation device, built by the Enviro-Clear Company, was introduced commercially quite recently. Adapted from the sugar beet processing industry, the EIS clarifier combines the attributes of modern synthetic flocculants with bottom feed of the effluent into previously formed zone of flocculated solids. The newly flocculated feed, moving through this bed, causes additional agglomeration of the floccules present. In effect, the resident agglomerated solids zone acts as a filter bed, thus eliminating the free-settling zone normally present in conventional thickeners. The line of demarcation between the agglomerated solids and the effluent is very sharp and hence provides an interface for control of solids withdrawal. The capacity of this unit is said to be 8 to 10 times greater than for conventional thickeners.

First installation of this thickener was made at the GrapeVine Preparation Plant of U.S. Steel Corporation; there, a 35 foot in diameter EIS thickener is used to clarify approximately 3,850 gpm of feed containing an average of 3.7% solids. The overflow contained approximately 240 ppm of solids, and the underflow contained approximately 34% solids. Flocculant was added at the concentration of 6 ppm.

After determining the thickener design, the engineer is then faced with the real problem: What is to be done with the solids being pumped out of the thickener underflow? The viable alternatives are:

- impoundment,
- underground stowage,
- mechanical dewatering,
- thermal drying,
- incineration or
- chemical mixing.

13.2.11.2 Impoundment The techniques of impoundment construction and use have been discussed in detail in Section 13.2.2 through 13.2.9. However, under new laws, the use of impoundments or slurry ponds is being closely regulated and the building of slurry ponds has become a very expensive and time-consuming process, assuming the operator is fortunate enough to be issued a permit, is blessed with a certain amount of good dam building material, has the appropriate land and terrain and has a good report from the geomechanical analysis of the proposed site. In mining areas where these favorable conditions exist, an impoundment is still the least expensive alternative in closing a water circuit.

Impoundment makes closing a plant water circuit sound easy, but for those operators not fortunate enough to have building materials or good lying land readily available, the project becomes somewhat more complicated and expensive, particularly where the operator has to dynamite and excavate an area for the impoundment and then line the entire pond. At this point, the economics become such that other alternatives of closing a plant circuit must be investigated.

13.2.11.3 Underground Stowage The second easiest way to discard the thickener underflow or fine waste is to pump it back underground. Some operators employ this process on a limited basis and many are initiating a pre-planned mining program at newer deep mines to possibly allow for future pumping of waste slurry into old workings. Underground stowage necessitates better planning between the mining and preparation groups in order to insure proper mine support, barrier pillars and life expectancy of the void. This system of disposal will lag many years behind actual mining because entries must be driven to the dip and all equipment recovered before stowage can proceed. Along this same line, abandoned mines make an excellent area in which to pump if the operator is assured of relatively large number of voids in the mine, is positive that all the barriers between mines are still intact and has determined that the stowage area will not become a source of acid mine drainage or otherwise impact the ground water.

13.2.11.4 Mechanical Dewatering The accepted methods of dewatering a thickener underflow fall into the category of mechanical dewatering which includes filters, centrifuges and high speed screening devices. Historically, each method has had various problems. Disc filters have been hampered by a poor release and low tonnage when filtering refuse. This situation has been helped by the use of different construction materials for filter bags and the "snap blow" process frequently found in dewatering other mineral concentrates. Drum filters have been used on a limited basis in the coal industry. Other industries, particularly sewage plants, are using the drum filters with much success on minus 10 micron particles.

Pressure filters have been used in Europe for a number of years, but have not been installed in this country yet (U.S. Steel may be in a prototype stage). This type of filter has been found to produce a relatively dry filter cake and a solid free effluent. Table 13-5 compares the important pressure filter elements versus the same elements in a disc filter needed to produce 30 tons per hour of dry solids from a 30% solids feed.

Table 13-5

Pressure Filter Use vs Disc Filter Use

	Pressure Filter	Disc Filter
Feed	30% solids	30% solids
Dry Tons per Hour	30	30
Cake Moisture	20 - 23%	35 - 40%
Capital	$2.4 million	$200,000

Source: M. J. Gregory, Manager-Preparation
North American Coal Corporation, Powhatan Point, Ohio

It is obvious from Table 13-5 that although the pressure filter produces a much more desirable cake, the capital cost is appreciably higher than a disc filter. The operating costs are also higher because of the semi-automatic cyclical nature of the filter which requires nearly constant attendance by an operator.

EIMCO Envirotech is testing a horizontal belt type vacuum filter with steam as a filter aid. In laboratory tests, reportedly, they were able to dewater 200 to 400 pounds of feed per hour per square foot of active filter area to a final moisture content of 7 or 8% on cleaned coal samples. It is possible that the horizontal belt type filter may be applied to fine refuse solids.

The conventional BIRD centrifuge has been modified recently in an attempt to close the preparation plant water circuit. The solid bowl centrifuge for coal refuse dewatering has typically been a low tonnage machine whose effluent usually contains a fair amount of extremely fine solids which were recirculated to the thickener and sometimes resulted in a solids buildup. By increasing the pool depth and moving the solids concurrently, a test model of the new "H" series centrifuge has proven a solids recovery in excess of 99.9%. The unit is now available in 15 and 30 ton per hour sizes (see Figure 8-11).

When handling the refuse material described earlier, mechanical dewatering devices cannot process as much tonnage as they could if a cleaner material, i.e., one with a majority of the suspended solids settled out of solution, was being dewatered. Both filters and centrifuges are affected in a similar manner. To help increase the capacity of these units, polymeric flocculants are used to accelerate the settling of the suspended solids. Polymeric flocculants have a proven ability as dewatering aids, but are relatively expensive and must, therefore, be selected and applied carefully. Typically, flocculants applied to materials analyzing 70% minus 200 mesh producing filter cakes between 30 and 40% moisture have ranged in costs from $0.005 to $0.35 per ton of refuse solids recovered: The higher the ash content of the refuse, the higher the chemical additive costs. Additionally, as demonstrated in Figure 13-26, the addition of more and more polymer does not insure an increase in solids recovery and an accompanying dryer product from the dewatering mechanism (in this case a filter). In fact, if too much polymer is added, the risk of producing a filter cake that holds more moisture is created and the resulting cake becomes excessively difficult to handle. Consequently, it is advisable to operate a thickener at a less than optimum condition when using polymer in order to compensate for the frequent swings in refuse tonnage being treated.

Most mechanical dewatering processes involving refuse material are menaced with one major problem if they achieve near success in closing the water circuit--the dewatered material contains a high percentage of moisture and is usually difficult to handle. The solids are in a semi-fluid state and cause problems on haul roads and particularly in disposal areas. Heavy equipment is unable to maneuver over the material and an attempt to mix coarse refuse with this material results in the entire refuse pile becoming unstable. Segregated disposal is also difficult because the area containing the fine refuse material is useless for additional dumping or grading until further dewatering is accomplished by evaporation or natural runoff, generating unwanted fugitive water emissions. Because of this problem, further dewatering may be necessary to accomplish the objective of a closed water circuit.

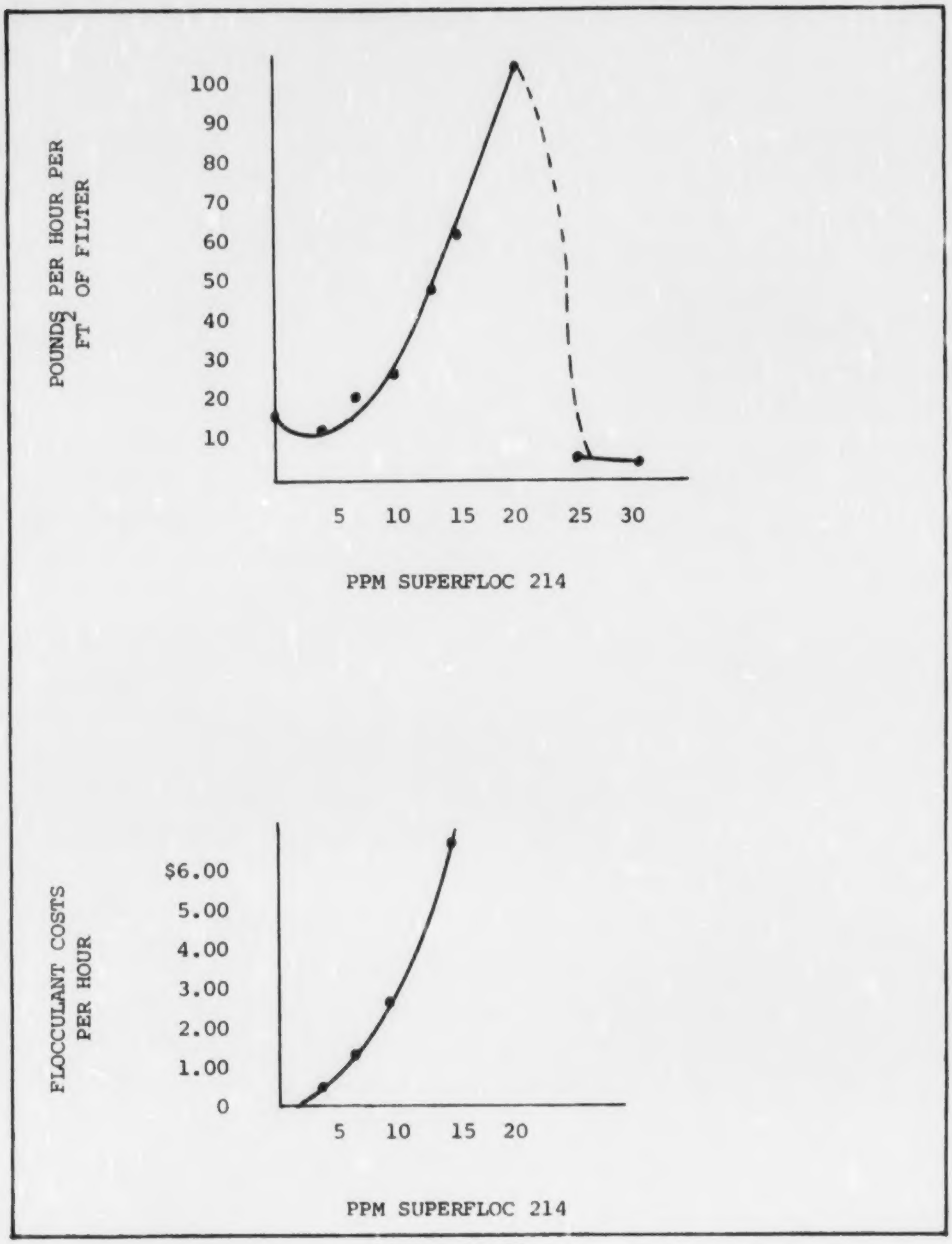


Figure 13-26
Impact of Polymer on Solids Recovery

13.2.11.5 **Thermal Drying or Self-Incineration** There are numerous approaches to dewatering refuse tailings by thermal methods, all of which require technical and economic assessment on a case-by-case basis. Both direct heat and indirect head contact systems have been studied experimentally. Generally it is felt that neither the direct nor indirect dryer system has strong potential application in successfully dewatering fine refuse slurry as generally both produce a product that though dry, still lacks characteristics attractive for subsequent handling and final disposal and because of the tremendous added capital and operating cost of a secondary thermal dryer and particulate recovery system. However, North American Coal Corporation has successfully thermally dried a fine refuse material containing:

Moisture	29.3%
Dry Solids	70.7%
Ash	35.72%
Heating Value	8,700 Btu/lb. Total Dry Solids

using the Denver Holo-Flite Conveyor. The unit was successful in drying the material, but is more economically feasible drying fine coal than fine refuse.

Thermal approaches to dewatering are available, however, that are uniquely different than that of just drying the material. These systems are the fluid-bed calcining agglomerator and the multiple-hearth incinerator. Pilot plant tests have indicated that when a mechanically dewatered refuse slurry of 35 to 45% moisture is introduced to a multiple-hearth incinerator and ignited, it can consume itself and generate enough heat to pre-heat and ignite the incoming feed. According to John Anderson of U.S. Steel Corporation, solids having over 50% ash and less than 9000 Btu per pound (dry) have successfully burned autogenously. M. J. Gregory of North American Coal Corporation found that self-incineration was maintained on a refuse material containing the following:

Moisture	31.0%
Dry Solids	69.0%
Volatiles	15.0%
Fixed Carbon	34.2%
Ash	51.0%
Heating Value	6,000 Btu/lb. Total Dry Solids

The multiple-hearth incinerator or roaster has been utilized in the mineral industry for many years. It requires only enough oxygen through a very low-velocity air supply to provide a slightly excess oxygen mixture for partial carbon combustion and to offset radiation losses. The product produced is in the form of a highly stable, non-weathering semi-clinker bearing a size consist of about 90% 2" x 1/8". Experimental results indicate that stack emission particulate limits and SO_2 emission limits are satisfactorily attainable. Throughput rates on a wet basis appear to be in the range of 18-24 lbs./ft.^{2} per hour.

The fluid-bed agglomerator is a modification of a fluid-bed drying unit in which refuse slurry is injected into a previously heated fluidized bed of inert material. If the refuse slurry contains sufficient Btu's and is metered in at a balanced rate within a range of about 37 to 44% solids, maintenance of heat availability for autogenous combustion of the refuse solids can occur on a steady-state basis without auxiliary fuel needs. As the system stabilizes and the carbon is consumed, ash pellets are formed and are released for disposal from the fluidized bed at a system controlled rate and in a stable, non-weathering form.

13.2.11.6 Chemical Additives The possibility of adding chemicals to the waste water slurry which will produce a residual solid of substantial strength while allowing the process water to be freed and recirculated to the plant as makeup water is being investigated by the Dravo Corporation. It appears from initial investigative reports that this process may have merit particularly where mechanical mechanisms cannot handle 100% of the plant load.

Addition of the solids reagent to a refuse slurry amenable to the treatment results in a chemical bond between the slurry solids and the water associated with the slurry. A cementation reaction occurs with the solids taking on a set within a relatively short time and developing an increasing strength. Most of the water combines reactively with the solids. Following the set time period, the solids become readily handleable if further transport is desired or if allowed to remain at the initial location of deposit, will set progressively harder to the point of being absolutely stable and non-weathering. This would permit repetitive disposal-set cycles upon previously stabilized deposits.

Provided the nature and characteristics of the refuse solids permit reaction with the reagent (and many coal refuse slimes do) the treatment requires little capital expenditure, however it has been determined that often up to 10% by weight of reagent must be added to the dry solids in the slurry to effect results. Furthermore, it has been determined that the higher the percent solids concentration of the slurry being treated, the faster and more successful the set reaction, and the smaller the percent of reagent that must be added. The minimum solids concentration level for effective cementation appears to be about 35% with significant improvement in results at 40% solids.

13.2.12 Preparation Plant Process Water

The water used in coal preparation operations is usually obtained from one or more of the following sources:

- rivers and streams,
- mine water and wells,
- public supplies,
- captured surface runoff water and
- treated water from slurry ponds or collection ponds for fugitive water effluent from waste deposits or plant sites

In some instances, coal preparation plants may be located near a stream in which case the use of this water is highly advantageous primarily because pumping costs are low and no treatment is generally required. Waste water from coking plants located near preparation plants has been used in some fine coal circuit installations. Other preparation facilities, located near power plants, may utilize the water from the power plant cooling circuit--although this water may be higher in temperature than surrounding rivers and streams, it is generally less costly and possesses distinct advantages in several preparation processes. Usually, clean streams void of contaminants from sewage, organic matter or acid drainage are acceptable as sources of water. In most cases, however, the water is obtained at the lowest cost including any treatment that is necessary.

The consumption of water per ton of coal treated in the individual plant varies over a wide range depending upon availability of local water, cost of the water, the type of cleaning process, whether or not the plant water cirucit is open or closed, the quality of the feed water and the requirements of effluent treatment prior to release of the water to a natural drainage system if the plant water circuit is open. Although appreciable savings of water can be achieved by the addition of plant water clarification systems, the amount of water required for coal preparation has been increasing over the years, particularly due to the increasing complexity of preparation process.

The water quality has some effect on all the operations in preparation plants. Changes in water quality during coal preparation occur as fine coal and mineral particles, such as clays, become suspended in plant process waters. These particles vary in size from 28 mesh to colloidal dimensions. It has generally been agreed upon by water scientists that particles from 0.1 to 74 microns determine the properties of water. It has also been determined that concentrations of solid matter in preparation plant wash water should be less than 5 percent or between 30 to 110 grams per liter. The primary disadvantages of using water charged with solids during the coal cleaning process are:

- The solids cause excessive wear, chiefly on pumps and cyclones by erosion.
- The solids may alter the density of the cleaning process (bath) and may increase the viscosities of the heavy media used in the separation process.
- The solid laden waters do not adequately rinse the washed products.

The rapid increase of froth flotation has introduced a new aspect of water treatment requirements. As indicated in Chapter 7, most cleaning processes in use in preparation plants do an acceptable job down to 48 mesh. A large percentage of the 48 mesh to 100 mesh fractions of coal now produced is being sent to the settling ponds or recovered in closed water systems as refuse. The trend is that more operations are resorting to froth flotation to recover the fine size coal, with the result being that, in addition to the suspended solids in the process water, the action of dissolved minerals or salts in various promoting agents that are added to enhance flotation, flocculation and filtration significantly effect the properties of the process water. Also, run-of-mine coal contains varying amounts of minerals and soluble salts. Some minerals and salts such as chlorides and sulfates of the alkalais and alkaline earth metals dissolve easily in water. Under certain circumstances, the salts will significantly change the pH of the circulating water. For example, calcite, aragonite and dolmite are slightly soluble to the extent of 14 parts per million in pure water at 25° C. The influence of additional salts present in solution increases the solubility of carbonates. Thus, sodium cholride in concentrations of up to 7% by weight can increase the solubility of calcite by 3.8 grams per liter. However, if the water contains carbon dioxide, or if any additional acid is present, the carbonate will neutralize the acid to a value proportional to its concentration. Soluble clays may also exhibit basic properties. It is conceivable for pyrite, marcasite and other sulfites that are normally insoluble in water, to oxidize and to form ferrous sulfate and sulfuric acid. The oxidation of iron sulfite has serious effects on pH, normally lowering it to between 2.8 and 5. Iron sulfate is sometimes used as an agent to promote the action of flocculant electrolites. The addition of salts, through either artificial or natural means will increase the conductivity of the solution.

A variety of processes, both physical and chemical, are being used to clarify plant process water, depending upon the undesirable characteristics of the water. If the process water consists only of suspended solids, typical of many cleaning plants, settling ponds or lagoons are constructed near the active operation. Water is directed into the ponds and the solids are allowed to settle. The ponds should be large enough to handle peak flows expected at the site. The clear effluent is decanted and recycled back into the cleaning plant, or it is discharged into the nearest natural drainage facility.

Large ponds can be constructed which can be used for many years, or several smaller ponds can be constructed in parallel. If the large pond is used, provisions should be made to cover the solids in the pond after it is filled and abandoned, otherwise the dry and fine solids can be picked up by high winds and create an air pollution problem. Covering the solids with clean earth, fertilizing and planting grass is an effective way of completing the job.

If land space for ponds is not available, thickeners are generally used. The overflow from the thickener is usually recycled back into the cleaning plant, but if sufficiently cleaned, it can be discharged into the streams. Underflow from the thickener is pumped to a black water pond for final disposal.

When the process water consists only of suspended solids and acids, with little or no iron, acid neutralization operations can be used with finely ground limestone (calcium carbonate). However, the reaction product is gypsum (calcium sulfate) which coats the limestone and makes it unreactive. Therefore, when using limestone to neutralize non-iron containing process water or collected fugitive acid mine drainage, the use of a rotary tub-type mixer is recommended to grind away the gypsum that sticks to the limestone. The neutralized water is then directed to a settling pond or lagoon for solid separation, with the effluent discharging into the stream or recycled into the cleaning plant.

If the process water or collected site fugitive water contains large amounts of dissolved iron, two types of treatment plants can be used depending upon whether the water is acid or alkaline. If the water is alkaline, it is simply aerated (either neutral or forced) in a large lagoon. Upon aeration, the dissolved iron changes into an insoluble form called ferric hydroxide, or yellow boy, and it can be separated from the water in a settling pond.

Although the process itself is simple, high volumes of iron-containing sludge are formed. The sludge can present serious disposal problems, particularly in mountainous areas where land suitable for ponds is scarce. Under certain favorable conditions, sludge has been pumped back underground into worked out sections of an active mine or into properly sealed abandoned mines. The sludge may also be transferred into worked out strip pits and covered with spoils and topsoil during the normal reclamation of surface mining operations.

If the water is acidic, a chemical treatment plant may be built adjacent to the preparation plant. Hydrated lime (calcium hydroxide) or quick lime (CaO) is added to the acid water, followed by a forced aeration. The water then passes into a pond where sludge settled out to the bottom and a clear overflow is discharged into the stream or returned to the plant.

The use of lime generally leaves the water saturated with dissolved salts which, in many instances, tend to scale equipment and piping, leading to high maintenance and repair costs. Other alkali chemicals such as caustic soda (sodium hydroxide) or soda ash (sodium carbonate) will decrease scaling but have found only limited application due to their high cost.

13.2.13 Coal Waste Disposal Summary

As is portrayed in Figure 13-27 and discussed in detail in Sections 13.2.1 through 13.2.12, there are a multitude of techniques for handling coal refuse disposal and its associated pollution problems. The costs of coal refuse disposal and the associated stabilization of the refuse deposits will vary widely and will depend upon the quantity of refuse, the size of the refuse, the availability and type of disposal site, the amount of potential pollutants present, the ease of control of the pollutants and varying meteorological conditions. Every solid refuse stream or associated water pollution problem is a special case and must be thoroughly investigated before the treatment process is selected.

13.3 AIR POLLUTION CONTROL

As stated in Chapter 12, the air pollution from coal preparation plants relates primarily to particulate emissions, including fugitive dust from the transportation, such as haul-roads, and from the bulk handling of coal and coal waste products as well as the particulate emissions from the thermal drying processes and from uncontrolled refuse pile fires. There is also additional air pollution in the form of gaseous emissions from the thermal drying processes.

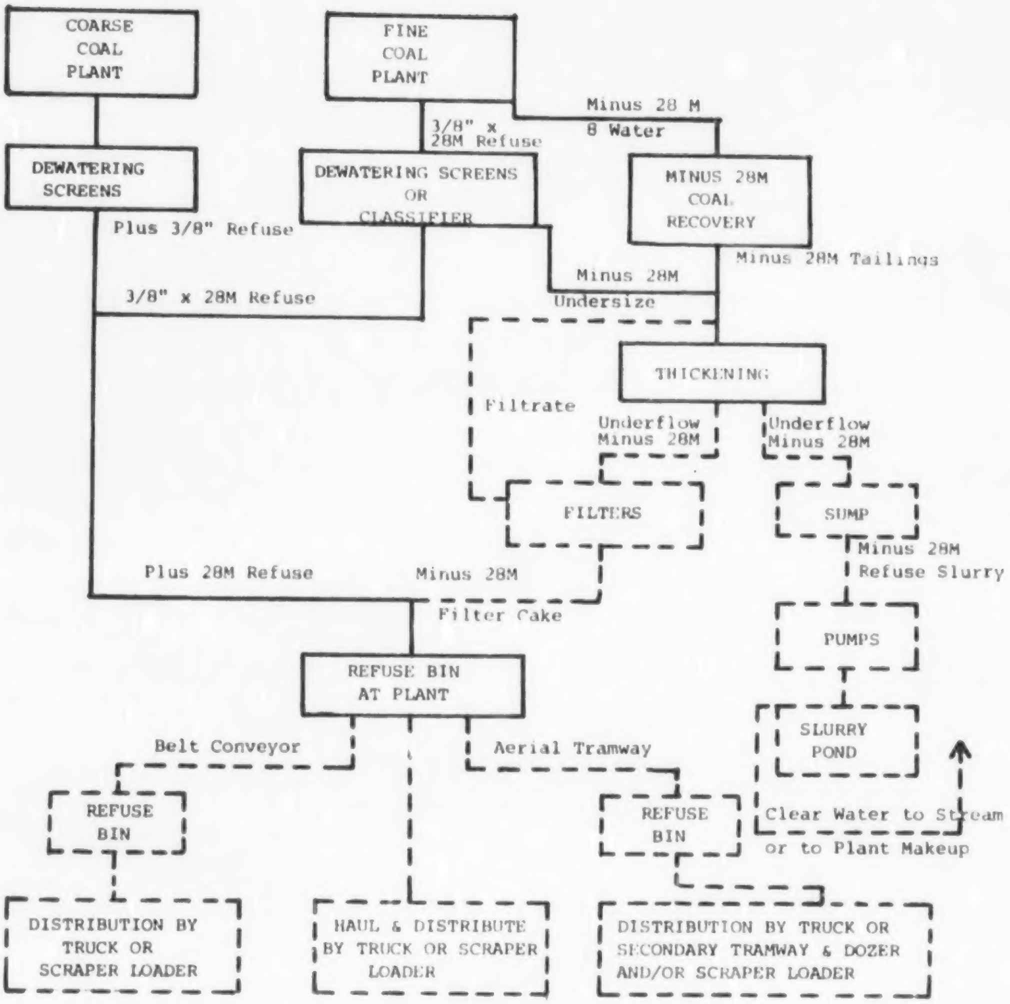


Figure 13-27

PLANT REFUSE REMOVAL AND SOME OPTIONAL METHODS OF DISPOSAL

13.3.1 Summary of Proposed Air Quality Standards

Standards of performance have been promulgated for new coal preparation plants. The standard limits emissions of particulates (including visible emissions) from the following sources, which are the affected facilities: Thermal dryers, pneumatic coal cleaning equipment (air tables), coal processing and conveying equipment (including breakers and crushers), screening (classifying) equipment, coal storage, coal transfer points and coal loading facilities.

The standards apply at the point(s) where undiluted gases are discharged from the air pollution control system or from the affected facility if no air pollution control system is utilized. The standards for these sources would limit particulate emissions to the atmosphere as follows:

- Particulate Matter from Thermal Dryers
  1. No more than 0.070 gram per dry standard cubic meter (0.031 grain per dry standard cubic foot).
  2. Less than 20 percent opacity.
- Particulate Matter from Other Affected Facilities

  Less than 20 percent opacity.

Most states do not have specific air pollution limitations for coal preparation plants but rather make them subject to a general process weight regulation. Three states do, however, have codes applicable exclusively to coal preparation plants. The most restrictive is 0.02 gr/dscf for thermal dryers--this regulation does, however, permit exit concentrations to increase with decreasing capacity. In addition, all coal producing states have a general visible emission restriction which limits all sources to a maximum 20 percent opacity.

13.3.1.1 Selection of Pollutants for Control Emissions from thermal dryers include combustion products from the coal-fired furnace, but these quantities of emissions are a small fraction of the particulates entrained by the flue gases passing through the fluidized bed of coal. During testing operations preceding the publication of EPA 450/2-74-021a, initial emission samples from thermal dryers were analyzed for products of combustion and heavy metals. Table 13-6 presents the results of the analyses of combustion products. The table permits a comparison with the standards of performance for coal-fired power plants.

Both NO_x and SO_2 emissions were found below the performance standards required of new coal-fired power plants. Admittedly, the dryers tested were processing (and using as fuel) low-sulfur coal. However, only 12 percent of all thermally dried coal is greater than 2 percent sulfur, primarily because thermal drying of lower quality coals is not generally an economically attractive alternative.

Table 13-6

Combustion Product Emissions from Well-Controlled Thermal Dryers

Pollutant	Concentration, ppm	Emission rate lb/(Btu x 10^6)	Coal-Fired Power Plant[a] lb/(Btu x 10^6)
NO_x	40 to 70	0.39 to 0.68	0.70
SO_x	0 to 11.2	0 to 0.09	1.20
HC (as methane)	20 to 100	0.07 to 0.35	--
CO	50	30	--

[a] Standards of Performance for Fossil-Fuel-Fired Steam Generators as Promulgated in 40 CFR 60.40

Source: EPA Publication EPA 450/2-74-021a

Finally the wet scrubbers used to control particulate emissions from thermal dryers also appear to control SO_2 emissions. The two dryers tested emitted SO_2 at 0-10 percent of the levels expected, based on firing rate and fuel sulfur content.

13.3.2 Applying Dust Collection Equipment to the Coal Cleaning Process

A coal preparation plant has several incentives besides the law to strive for good dust control, including the elimination of a nuisance and providing more pleasant working conditions, the reduction of maintenance cost and lost time due to unnecessary machine wear, the elimination of a major safety hazard and the recovery of a salable product.

Whenever a preparation plant utilizes thermal drying, dry screening, crushing, transfer points or silo storage, there should be some type of dust collection equipment to capture and remove the dust.

The non-stack fugitive emissions from coal utilization processes occur from operations in which coal or its products are stored, transferred or reacted. Wind-blown dust from coal piles is one example of a fugitive emission, as is smoke from a burning coal waste disposal pile. Run-of-mine coal is transported (by truck, conveyor or railroad car) to the preparation plant. This transport and the subsequent transfer to a storage pile or silo are the first opportunities for fugitive emissions (coal dust).

Open pile storage can be subject to wind-blown coal dust losses. If the pile is dry and the locale is subject to high and frequent winds and pile working, the losses can be serious. Unless outdoor conveyors and transfer points are enclosed, coal being transferred to the crushers and screeners can be a source of wind-blown coal dust. The final transfer of coal to the rail cars or trucks, and its subsequent transport to the user, is the last potential source of fugitive emissions.

There are three principal methods available for the measurement of fugitive emissions. Each is designed to sample a specific class of fugitive emission. The methods and their applications can be summarized as follows:

- Quasi-Stack--A duct and fan are fitted to capture the emissions from a local source. Standard stack sampling methods are used for analysis. Point sources such as storage silo leaks, materials pouring, etc. are readily measured using this sampling method.
- Roof Monitor--A vent or roof monitor used for venting of a building or enclosure is used as an air sample source. Ambient air monitoring equipment is used to measure the emission flux through the monitor or vent. Flow measurements using anemometers can thereby be used to develop mass emission rates for the building or enclosure. This is therefore best used for indoor, tightly enclosed structure fugitive sources.
- Upwind-Downwind--A meteorologically based sampling array is used to determine the emission flux into and out of an open source. A three-dimensional network of ambient air samplers upwind and downwind of the source serves to determine pollutant concentrations. Knowledge of wind speed and direction allows determination of the emission rate. There is a need in many cases to also run tracer tests and use diffusion modeling to refine the results. The environmental impact of outdoor and multipoint complex sources can be evaluated in this manner.

One of the most important tasks is to match the fugitive emission source to the sampling methods and control methods most adaptable to that source. Fugitive sources most amenable to measurement by the quasi-stack method are readily controlled by use of a permanent hood and duct.

Those sampled through roof monitors can best be controlled by treatment of the individual in-plant sources which produce the emission or, if necessary, the roof monitor vent air itself. Those outdoor sources for which upwind-downwind sampling techniques are applicable can be controlled by such methods as enclosing individual sources (e.g., transfer points) and ventilating through a control system, placing operations creating fugitive emissions in a building, improved maintenance, use of surface active agents on exposed material piles, planting of vegetative covering and paving and wetting of dusty plant roadways. In addition, scheduling of operations to avoid fugitive emissions could be considered as a method of administratively controlling these emissions. An example would be to avoid coal reclaiming on those days when wind direction and speed and surface dryness would maximize fugitive emissions and their impact on surrounding areas.

Table 13-7 is a matrix of the probable fugitive emission sources, feasible sampling strategies and potential control methods for a coal preparation plant. For overall plant emissions, which will thereby establish its impact on ambient air quality (stack and fugitive emissions), an upwind-downwind sampling method is useful. It must be used with tracers and modeling to serparate the coal dryer stack emissions from the fugitive emissions. For individual fugitive emission sources, quasi-stack or upwind-downwind strategies are the most applicable. Although the upwind-downwind strategy can be used for individual sources, some tracer and modeling work must be done to separate individual source contributions.

Table 13-7

Fugitive Emissions from Coal Preparation Plants

Probable Source	Feasible Sampling Strategies	Potential Control Methods
Coal Transport to Plant and from Plant	Upwind-Downwind	Cover railcars, trucks or conveyors
Coal Storage Piles	Upwind-Downwind	Use silos, wet pile, build windbreaker
Stacker-Reclaimer	Quasi-stack or Upwind-Downwind	Cover conveyor, hood reclaim wheel
Coal Conveyors	Quasi-stack or Upwind-Downwind	Cover conveyors, hood transfer points
Crushing and screening building	Roof monitor or Quasi-stack	Enclose and treat building vents, hood transfer points
Waste Fines transfer	Quasi-stack	Cover conveyors, hood transfer points
Waste storage	Upwind-Downwind	Use silos, wet pile, build windbreak, use vegetation cover
Gob Pile Fires	Upwind-Downwind	Control dumping, dilute waste with inerts
TOTAL PLANT	Upwind-Downwind	See individual sources

13.3.2.1 Exhaust hoods The use of exhaust hoods over dust sources such as transfer points, screens and crushers is the usual method of keeping the dust out of the plant air and off the coal product. A minimum exhaust air velocity of 300 feet per minute over the total opening is usually effective in preventing the escape of all objectionable dust. For best results, hoods must be very carefully designed to utilize the direction of air currents produced by the flow of coal and movements of machinery. Since large air volumes are reflected in rather expensive dust-collecting equipment, it is important to design hoods having minimum opening and strong air motion close to the dust source and yet with sufficient clearance for passage of coal. It cannot be overemphasized that all hoods, cover plates and air ducts must be arranged for quick and convenient removal, for easy access to machinery and for cleaning purposes. In practice, many covers or enclosures have been removed permanently to save the time required for removing and replacing them. Air exhausted from hoods seldom contains the coarser dust particles, and the dust-grain loading of this air is usually low. This often permits the reuse of this dusty air for dedusting coal if such is practiced.

The desirability of recirculating the dusty air is apparent when one considers that the air quantities for exhausting from hoods are considerable.

13.3.2.2 Ducts Air ducts are required for transporting the dust-laden air from hoods or dedusters to the dust-collecting apparatus. To prevent settlement of coal dust an air velocity of 3000 feet per minute must be maintained for all dust sections where settlement is likely to occur, as in horizontal or slightly inclined sections and turns.

Ducts must be designed to carry the maximum amount of air that it is contemplated to use at a selected velocity and pressure. A material increase or decrease in the air velocity is sure to cause difficulties, either from dust settling in the ducts or from insufficient fan and motor capacity. In doubtful cases a duct larger than required is preferable, as its area may be reduced by installing baffles at suitable intervals from the top side of the duct. Branches must enter the main duct at an angle of about 30 degrees, but never exceed 45 degrees, preferably near to the top and in the tapered section of the duct. The inside of the duct must be smooth and free of projections. Laps of joints should be in favor of the air flow.

Bends and elbows are commonly designed with a radius of not less than twice the diameter of the duct. Wear from abrasion is very severe on short radius turns. Airtight clean-out openings should be provided along the bottom of the duct where dust might settle and always where the dust changes directions or a branch enters. Duct sections should be equipped with airtight joints readily taken apart, either of the flange type with gaskets or the removable band type. Ducts must be built of sheets heavy enough to resist abrasion and also suction pressure without pulsating. All dust-collecting equipment must be strong enough and supported sufficiently to be safe if accidentally filled with dust. Each dust installation has its own particular problems that must be solved; vibration from other units is one of them. In extreme cases it may be necessary to use flexible connections between pipe sections.

13.3.2.3 Mechanical Collection Equipment The types of mechanical dust collection equipment may be broadly grouped into six general classification types:

- Gravity Settling Chambers--A gravity settling chamber is, essentially, a relatively large compartment into which a dust laden gas stream enters to have its velocity greatly reduced so that particles can settle out by the force of gravity. This means of collection is effective only for relatively coarse particles, since the gravity settling rate of fine particles is extremely low. For example, a coal dust particle of 100 microns in diameter will settle at a rate of about 70 feet per minute, a 10 micron particle will settle at a rate of about one foot per minute and a one micron particle will settle at a rate of about 0.01 feet per minute.
- Inertial Separators--An inertial separator utilizes the difference in inertia between a gas stream and the heavier suspended particles by effecting a sudden change of direction of the gas flow stream.

- Centrifugal Collectors--Centrifugal or cyclone collectors employ centrifugal force to separate the suspended particles from the gas stream. As with the coal washing equipment of similar design, the dust laden gas stream enters the cyclone cylinder tangentially. The resulting centrifugal force throws the dust particles to the wall of the cylinder while the gas stream spirals upward to an inner vortex and is discharged axially through an outlet port. The dust particles fall downward into the cone and are removed.

- Wet Scrubbers--This term is applied to a wide variety of equipment using various mechanisms to bring about contact between dust particles and water. The objective of wet scrubbers is to cause the small dust particles to adhere to larger droplets of water so that the effective size of the dust particles is greatly increased, enhancing their separation by mechanical means such as impingement or inertial separation. To increase the probability of contact between dust particles and water in a scrubber, the water is usually introduced in the form of a fine spray. As they incoming gas stream and suspended particles encounter the water droplets, the gas flows around the droplets but the particles, due to their greater inertia, tend to impinge on the droplets.

- Fabric Filters--In the fabric filter, the gas stream with its suspended particles is passed through a woven fabric at low velocity. The fibers that comprise the fabric offer obstacles to the flow and thus intercept the dust particles. There are two primary types of bag filters, the tube or bag type and the envelope type. In the tube type, the individual filters are cylindrical tubes, usually from five to 12 inches in diameter and up to 30 feet in length. The individual filters of the envelope type are cloth forms stretched over a rectangular frame.

- Electrostatic Precipitators--In the electrostatic precipitator, the dust particles are electrically charged by means of ionization of the carrier gas and transported by the electric field to collecting electrodes. The particles are then neutralized on the collecting surfaces and removed for disposal. The major components of an electrostatic precipitator are: a source of high voltage current (up to 70,000 volts), an electrode system, an enclosure to provide a precipitation zone and a system for removing precipitated dust.

Each of these general categories have advantages or disadvantages based upon their application to specific problems. As indicated, the gravity settler is primarily a large particle size collector. Because of its low efficiency on fine dusts, the gravity settler is seldom used for recovery of coal dust except where it can effectively remove coarse, abrasive particles ahead of a more efficient collector. Likewise, the inertial separator is very inefficient for separation of small particles and thus is of little value considering the present day requirements for dust collection.

On the other hand, the cyclone collector is one of the most widely used types of collectors in coal preparation plants, even though the efficiency drops off rapidly at about the 10 micron size levels. If the incoming gas flow is increased in a given cyclone, the velocity of the particles is also increased, thereby improving the separation capability of the cyclone. However, increased velocity also results in increased pressure differential and higher power consumption. Concurrently, the separation force is inversely proportional to the radius of the cyclone. Thus, for any given cyclone velocity, a cyclone of smaller radius will be more efficient at removing smaller particles than will a cyclone with a larger radius. Therefore, to achieve high efficiencies with cyclone collectors, a large number of small radius cyclones in parallel may be employed instead of a single large cyclone tube. It must be remembered that within a cyclone, there is always considerable turbulence because the outer vortex is moving downward, while the inner vortex is moving upward. This turbulence causes some of the larger particles to be carried out with the exhaust gas. There is, therefore, an overlapping in the size distribution of materials caught and lost in cyclones.

With wet scrubbers, which include spray chambers, packed beds, wet cyclones, impingement scrubbers and orifice or venturi scrubbers amongst their numbers, practically any degree of efficiency can be attained, even on sub-micron particles, if sufficient energy is expended into the system. The necessary energy may be spent either to create turbulence in the gas stream or to break up the input water into a large number of small droplets and propel them at a high velocity into the gas stream; or, the energy may be expended as a combination of these methods where energy from a motor is used to intimately mix the gas stream and the water. In a spray chamber system, the gas stream passes through a water spray that may be cocurrent, countercurrent or normal to the gas flow with a minimal energy expenditure; however, recovery efficiency for small dust particles (those less than a few microns in size) is also low. In a packed-bed scrubber, the gas stream flows through a packing material usually concurrently to a stream of water to achieve contact over a large surface area, but requires more energy than a spray chamber. A packed scrubber as depicted in Figure 13-28 can produce high mass and heat transfer rates along with an ability to handle viscous liquids and heavy slurries. A two stage scrubber operating at a pressure drop of 8 to 10 inches of water gauge will collect 98% of the particles greater than one micron.

In a wet cyclone, the action is similar to that in a dry cyclone except that a stream of water is sprayed radially across the gas stream. The fine dust is flushed to the bottom of the vessel and discharged, and the clean air is spun through a fixed entrainment separator and

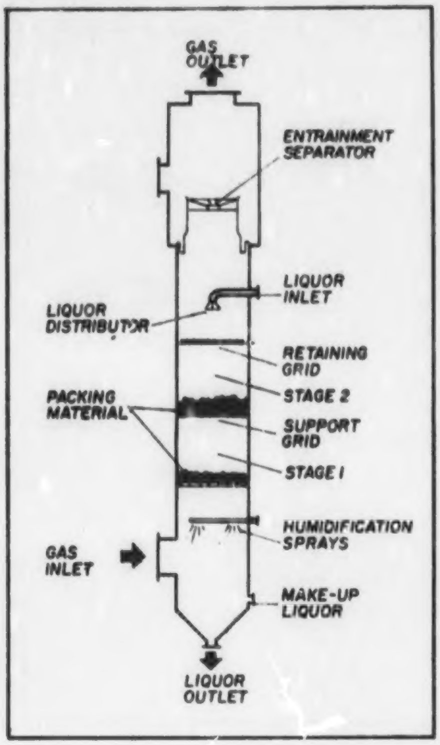


Figure 13-28

Surface Aera of Packed-Bed Scrubber

discharged to the atmosphere. In the impingement collectors, the gas stream impinges upon a reservoir of water and usually passes through the water to create a turbulent layer of bubbles, gas and dust, which results in a large contact area. A typical impingement scrubber design is shown in Figure 13-29. The gases flow upward through succeeding impingement plate stages and pass through a separator stage where the gas velocity is accelerated, casuing inertial separation of the retained water droplets. This type of scrubber can remove 97% by weight of particles above one micron in size with a gas velocity of 500 fpm at an operating pressure drop of 2 to 3 inches of water gauge per stage.

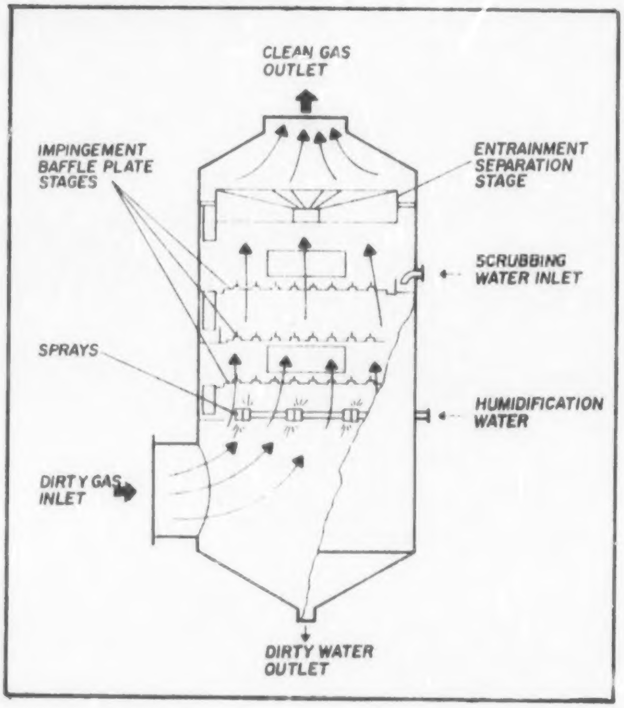


Figure 13-29

Typical Impingement Scrubber Design

In the so-called "high-energy wet scrubber", of which the orifice and venturi scrubbers are the prime examples, the gas stream passes at high velocity through a restricted opening, at which point water is also introduced. At the throat of the venturi, the gases, flowing at 12,000 to 18,000 fpm, produce a shearing force on the water stream which casues the water to atomize into very fine droplets. Impaction takes place between the dust entrained in the gas stream and the liquid droplets. As the gas decelerates, collision continues and agglomeration of the dust laden water droplets takes place. A venturi-type scrubber operating in a pressure drop range of 30 to 40 inches water gauge is capable of an almost quantitative collection of particles in the size range of 0.2 to 1.0 microns. As indicated, the general efficiency of wet collectors increases as the pressure differential across the restriction increases; however, a higher pressure differential also means greater energy consumption. As with all wet scrubbers, the resulting waste water slurry must be dewatered and the water purified for reuse.

The fabric filter has its application where high collection efficiency of extremely fine dust particles is required and where gas temperatures and humidity are moderate. Although bag houses operate at the highest collection efficiency levels (99.9+ percent), they also have serious limitations. For example, bag houses are probably one of the most expensive solutions and they usually require the most space for installation. On the whole, however, bag houses generally require much less energy to achieve their high-efficiency recovery and do not have water requirements.

Electrostatic precipitators are excellent for specific dust collection problems. The precipitators can collect small particles down to less than one micron in size with very low energy consumption and it can be built for high difficulties encountered when using an electrostatic separator in removing coal dust from air streams are due to high humidity of the incoming gas and the possibility of a spark discharge and the resultant explosion hazard.

13.3.3 Specific Applications to the Thermal Drying Process

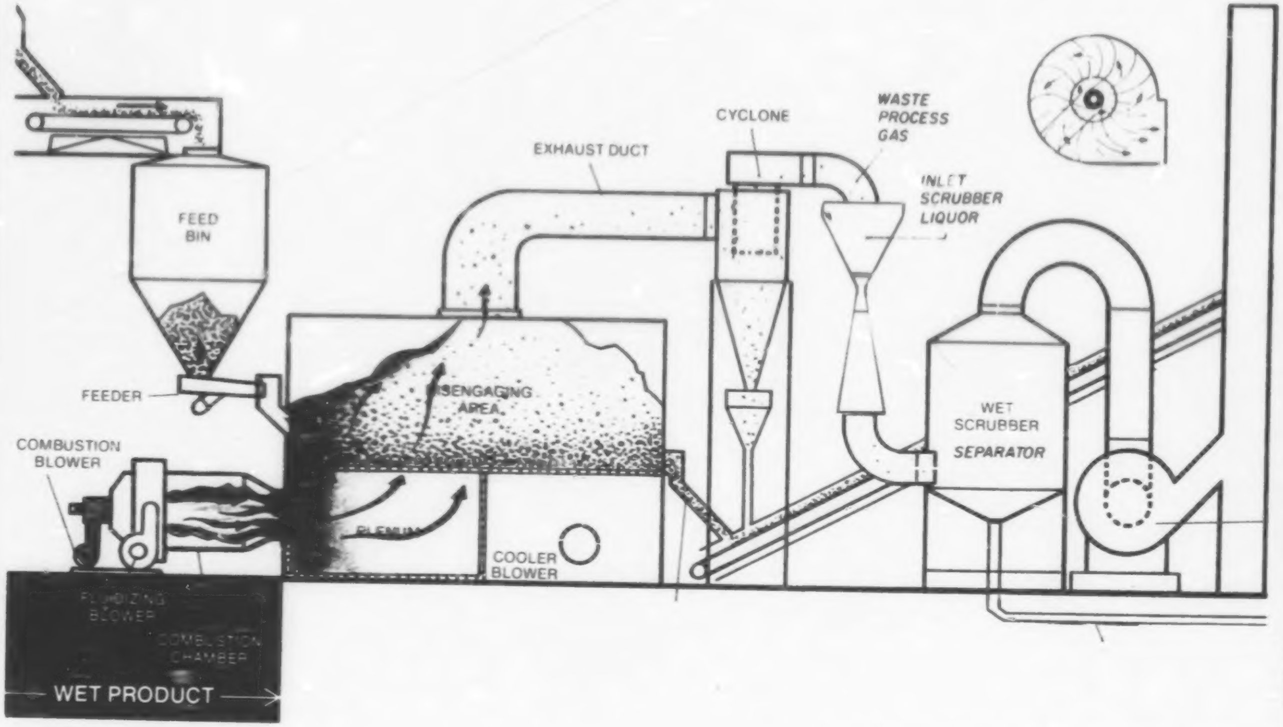
The most difficult air pollution problem associated with the coal cleaning operation is the control of the thermal dryers' emissions. The exhaust air with temperatures up to 200° F. normally contains a great quantity of fine particulates from the drying process and from the combustion process and usually has a high moisture content. While a cloth collector would provide the desired cleaning efficiency at a low pressure drop, the temperature and moisture would present problems and make its reliability extremely doubtful.

Years ago, thermal coal dryers, including our present day fluid bed dryers, utilized only low pressure drop, medium efficiency collectors. Exit concentrations were in the range of 0.10 to 0.17 grains/dscf. With the recent reductions in the allowable discharges from these dryers, the coal operators have had to switch to a higher degree of collection efficiency which cannot be met by the low pressure drop, medium efficiency scrubbers. As a direct result, the high pressure drop scrubber has emerged as the only practical method to provide the required clean air.

As shown in Figure 13-30, the initial control device for thermal dryers is a dry centrifugal collector which retains up to 95% of the entrained fines and returns them to the coal product. All secondary emissions control systems are venturi type wet collectors. The venturi collector can be fabricated in a number of shapes and designs with great flexibility of operating pressure drop and efficiency. This equipment normally requires 6 to 8 gallons of water/1000 cfm and allows recirculation of slurry water up to 5% solids. The resulting water-dust slurry is easily fed to the clarifier thickener for recovery.

13.4 NOISE POLLUTION CONTROL

The primary noise-producing mechanisms in coal cleaning plant equipment are impacts, mechanical vibrations and aerodynamic and hydrodynamic sources. Of these sources, impacts are the most prevalent and include impacts of coal and refuse against steel or vice versa. Mechanical vibrations that are not the results of impacts occur due



J. J. DAVIS ASSOCIATES
MANAGEMENT ENGINEERS

Venturi Scrubber Shown as Part of a Complete Coal Dryer

Figure 13-30

DCN

to vibrating feeders and screens or unbalanced rotating equipment. Hydrodynamic or aerodynamic sources occur in pumps, compressors and values and consist of fluid pulsations or oscillators.

Two considerations are of importance in relation to the noise produced by coal cleaning plants:

- hearing damage to personnel employed in such plants and
- annoyance to people in communities near such plants.

The maximum permissible noise exposure of plant personnel is delineated by the Federal Coal Mine Health and Safety Act of 1969, where it states that the standards of noise prescribed under the Walsh-Healy Act shall be applicable to each coal mine.

The occupational noise exposure portion of the Walsh-Healy Act delineates the following:

- Protection against the effects of noise exposure shall be provided when the sound levels, measured on the A scale of a standard sound level meter at slow response, exceed the permissible exposure shown in Table 13-8.

Table 13-8

Permissible Noise Exposures Prescribed by the Walsh-Healy Act

Duration (hours per day)	8	8	4	3	2	1½	1	½	¼ or less
Permissible Sound Level (dBA, slow response)	90	92	95	97	100	102	105	110	115

For impulsive or impact noise, the maximum permissible sound pressure level corresponds to a measured instantaneous peak value of 140 dB.

- When employees are subject to sound levels exceeding these shown in Table 13-8, feasible administrative or engineering controls shall be utilized. If such controls fail to reduce the sound levels to the values listed in the table (or to lower values) personnel protective equipment shall be provided and used to reduce sound levels to the requirements of the table.
- If the noise is unsteady and involves maxima that occur at intervals of one second or less, the noise is to be considered as steady.
- In all cases where the sound levels exceed the values specified by the Act, a continuing, effective hearing conservation program must be administrered.

The noise dosage a worker recieves is determined by the ratio of the length of time the worker spends in a particular noise environment divided by the noise exposure in that particular environment. If the worker is exposed to several different sound levels, his total dosage would be the sum of each of the individual dosages. The equation for determining the dosage is:

$$D = \frac{C_1}{T_1} + \frac{C_2}{T_2} + \frac{C_3}{T_3} + \ldots \frac{C_n}{T_n}$$

where C is the actual duration of exposure at a given steady state noise level and T is the noise exposure limit for the level present during the time C. According to MESA (the Mine Enforcement and Safety Administration) regulations, the total dosage should not exceed unity (one) for any worker for a full day of work. Figure 13-31 is a graph of time and noise exposure expressed in hours per day to which a worker can be exposed to each (A) weighted sound level.

Most existing statutes governing industrial community noise prescribe maximum permissible A-weighted levels of 50 dB(a) for nighttime (10 p.m. to 7 a.m.) and 55 to 65 dB(a) for daytime, as measured at the boundaries of surroun-

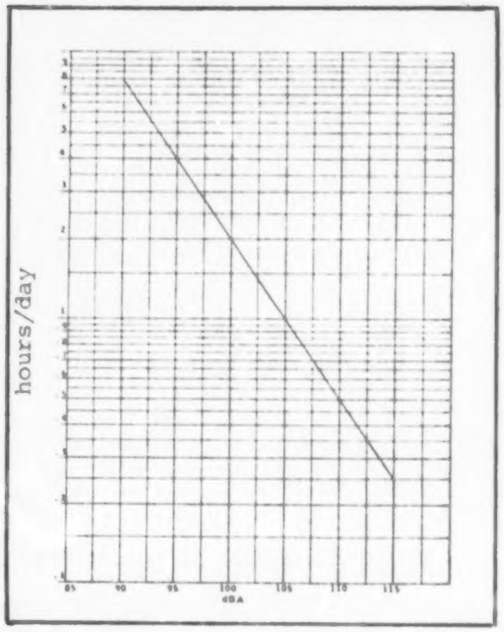


Figure 13-31

Maximum Daily Noise Exposure Permitted by MESA

ding residential areas. These values assume that the noise level fluctuates little with time; more stringent restrictions may apply for fluctuating noise levels. Since the noises emanating from coal cleaning plants tend to be essentially non-fluctuating, one may take 50 dB(a) for nighttime and 60 dB(a) for daytime operations--as measured at the community boundary nearest the plant--to be reasonable criteria.

Noise is defined simply as an unwanted audible sound. An audible sound is a disturbance or vibration of air sensed by people or wildlife. Anything that causes air to vibrate or anything that sets something else in motion which in turn causes air to vibrate may be considered a noise source.

Sound typically propagates from a source to a receiver, i.e, to a person or item of equipment whose noise exposure is of concern, via diverse paths. These paths may be very complicated, involving not only reflections but also conversions between vibrations of air and vibrations of structural components. For example, a noise source in an enclosure causes the enclosed air to vibrate, the air vibrations set the enclosure walls into motion, which in turn produces vibrations of the air outside the enclosure.

Virtually every noise problem may be approached conceptually in terms of three basic elements:

- sources,
- paths and
- receivers.

Noise control then, in essence, involves reduction of noise generation by the significant sources, reduction of the propagation of noise from the sources to the receivers along defined paths and/or rendering the receivers more tolerant to the noise. For example, rubber liners may be used to reduce noise-producing impacts of coal on steel chutes (reduction of noise generation at the source); enclosures may be constructed around noisy machinery (obstructing the noise propagation path); or the amount of time a worker can spend in a noisy location may be limited (making the worker more tolerant of a higher noise level without suffering hearing damage).

13.4.1 Reduction of Preparation Plant Noise

The majority of preparation plant functions are controlled from a central operator's position, with the operator at some distance from the equipment itself. Few items of equipment require by their nature immediate physical contact between a worker and the equipment or the coal being processed. Therefore, noise control enclosures would not directly impede the coal cleaning process. However, it is mandatory that preparation plant personnel see the flow of coal through chutes and screens and across table decks, thereby complicating the design of close-fitting enclosures and limiting their utility. In addition, the maintenance activities of a preparation plant frequently includes cutting and welding of worn or damaged parts. Therefore, noise reduction treatment applied to any surfaces subject to repair by these means must not impede torch-cutting either by being unsafe or by being prohibitively expensive to replace. Also, during routine maintenance of the plant equipment, it is often times necessary to move large items of equipment. This means that any noise control enclosure or partitions must have large doors, be accessible from overhead or be completely removable. The primary safety concern in any coal cleaning plant is dust buildup and the resultant fire and explosion hazard. Thus, fibrous acoustical materials which tend to retain dust cannot be used without expensive treatment. Additionally, all noise reducing installations must be designed for easy cleaning by water hosing.

An effective noise control program must first attack the noisiest sources. However, only those sources that contribute to worker exposure are important from the standpoint of industrial health. For this reason, the importance of quieting a noise source depends both upon the noise level and the proximity of the workers.

Table 12-7 presented a rank ordering of machinery, taking into account noise levels and the proximity of the workers under normal operating conditions. Although several sources offer conflicting ranking priorities, it is generally concluded that the most severe hearing damage-risk problem is associated with the car shakeout operations. The second most significant problem is associated with vacuum filter blowers and vacuum filter pumps. The third most significant noise control problem and the one contributing most to the structural vibration is associated with the vibrating screens used in abundance throughout the plant.

The following item by item discussion deals with specific available noise treatments applicable to various items of preparation plant machinery and are paraphrased from Coal Cleaning Plant Noise and Its Control prepared by E. E. Ungar, et al of Bolt Beranek and Newman, Inc. in 1974 for the U. S. Bureau of Mines.

- Car Shakeouts--The pounding of the shakeout mechanism against the railcar side cannot be reduced without reducing its efficiency for unloading the car. Padding of the contacting surfaces or clamping the shaker to the car sides would reduce the noise, but also the efficiency of the unloading operation. The only practical means for dealing with the noise of shakeouts consists of providing an enclosure for the shakeout operator and his helper. The enclosure must provide at least 40 dB(a) of noise reduction. Its walls and ceilings need to be built of massive panels, its door should be self-closing with airtight rubber seals and its window must be double-glazed.

- Vacuum Blowers and Pumps--The in-plant noise associated with the vacuum blowers and pumps comes primarily from the air inlets and discharges. The noise is typically dominant, pure-tone (single-frequency) components at frequencies that correspond to the rotor lobe or fan blade passage rates and harmonies of those. Noise control can best be accomplished by means of mufflers or ducts affixed to the ports. Where the predominant noise is a single tone at a fixed frequency, mufflers tuned to this frequency are quite useful. If the dominant noise consists of a multitude of pure tones and/or broadband noise, then a muffler consisting of a long, labyrinthe, acoustically lined duct is required for muffling purposes.

Screens--The simplest add-on method for reducing the noise generated by screens consists of building an enclosure around the screen. Noise reductions of 10 to 15 dB(a) may be realized with enclosures that also cover the driving mechanism. Few such installations are anticipated due to projected problems related to screen maintenance, screen observation difficulties or enclosure life and safety problems.

Replacement of the steel decks with rubber-coated or other resilient duct material would reduce the severity of impacts and the associated noise. Reductions on the order of 5 to 10 dB(a) may be expected for the impact-related component of screen noise, but the total noise reduction would be only between 2 and 8 dB(a). The performance and economic advantages and problems of rubber coated and similar decking are not clear. Although the initial cost is about three times that of conventional decks, the estimated life of the coated screen decks is projected to be between three and five times that of conventional steel decks.

Reduction of impact severity and the associated noise may be obtained also by reducing the stroke and speed of the shaking mechanism. However, the screens process flow capabilities will be greatly diminished, making this approach unacceptable.

Reduction of the noise contributed by the eccentric weight driving mechanism may be achieved by use of gearing manufactured to closer tolerances and tighter bearings. Additionally, covering the mechanism with a closely fitting enclosure that is acoustically lined and vibration-isolated from the case would offer noise reduction potential up to 10 dB(a); however, the associated cooling and maintenance problems are not known.

Where the noise is caused by a chattering of the screen supporting springs against the mounting pads or screen frame, insertion of a resilient pad between the spring end and the associated chattering point may produce a 5 dB(a) reduction.

Alternatively, replacement of the springs with air bags at a considerable expense would yield a 15 dB(a) reduction.

- Hoppers, Bins and Chutes--Impact noise reductions of about 5 dB(a) can be achieved by lining the hoppers, bins and chutes with rubber or similar covering although the availability, wear, repairability and costs are not known. A widely employed useful approach consists of placing welded ledges or similar obstructions to the material flow on the walls so that a protective layer of material remains in place to absorb the impact.

- Air Valves and Air Blasts--Water valves are not a significant noise source. However, air valves and blasts have significant noise levels. Air valves like those on Baum jigs tend to be extremely noisy due to the explosive and hissing noise associated with the venting process. The noise control methods for these air valves is the same as that for vacuum pumps and tends to be expensive.

  The air blasts that are used to aid material flow in chutes and hoppers generate loud hissing noises due to the high air exit velocity and the impingement of the air stream on solid surfaces. A velocity reduction of 20% should result in little loss of material moving but may reduce the noise level by several dB(a).

13.4.2 Control of Plant Noise Intrusion into Nearby Communities

As in most noise problems, the generally most effective means for control consist of reducing the noise at its source. The coal preparation plant noise that reaches nearby communities typically is due primarily to only a few items of machinery or equipment that are (a) much noisier than others, (b) located outside the plant buildings or near openings (doors or windows) in such buildings, and/or (c) located near the observation position. In most practical situations, the offending item(s) can be picked out simply by listening to the noise and by knowing the operating cycles and closed-in noise characteristics of the likely problem items.

Once the prime contributors to the observed noise have been identified, they may be quieted by the various applicable techniques that have been described in the previous section.

For items located inside plant buildings near openings, significant noise reduction can often be obtained by closing these openings. Where total closure is not feasible, i.e., because of ventilation or continuous accessibility requirements, operators may alternatively provide these openings with mufflers or barriers. Mufflers would in essence appear like tunnels or ducts extending from doors or windows, with acoustical lining on their insides. These tunnels and ducts should be curved or bent to eliminate all "line-of-sight" communication between the inside of the building and the outside, and they should be several times as long as their greatest cross-sectional dimension.

Barriers consisting of walls or panels placed outside of the doors and windows should also be placed so as to eliminate the possibility of line-of-sight contact between the inside and the outside. These barriers should not be flat and parallel to the building wall; they will work better if they are curved or accordion pleated. They do need to be covered with acoustically absorptive material on the side nearest the noise source, and they generally need to be considerably larger than the openings they protect.

Building walls that are of relatively lightweight sheet metal and/or plastic present little obstruction to noise. Since most of the noise goes through the walls, closing off of openings in such walls has no appreciable effect on the noise reaching nearby communities. In such cases, the needs to consider quieting of all of the noisy equipment in the plant and/or improving the plant walls by adding secondary, preferably heavy, walls outside the ones that are already there may have to be considered.

Where possible community reaction to noise is a problem, operators obviously should not reduce the in-plant noise produced by valves, and by air intakes and exhausts by ducting these to the exterior of the plant. If such ducting already exists and if the noise emanating from it may bother the community, mufflers should be added at the ends of these ducts.

Walls or earth berms constitute useful means for protecting communities from plant noise provided, however, that these are close enough to the noise source and large enough so that the shortest sound path around these barriers is longer by a considerable percentage than the most direct sound path in absence of the barrier. Thus, impractically large barriers are required to have a significant effect on communities located at considerable distance from the plant.

Weather, notably wind, temperature gradients and humidity also affect the long-range propagation of sound. Particular combinations of conditions enhance this propagation, others impede it. The operator may always expect occasions where sound refracted by the atmosphere greatly reduces the effectiveness of a given barrier installation.

REFERENCES AND/OR ADDITIONAL READING

Akers, David J., Jr.; & Moss, Edward A.; "Dewatering of Mine Drainage Sludge -- Phase II", Office of Research and Monitoring, EPA R2-73-169, February 1973

Altmare, Philip M., "The Application of the Tall Stack and Meteorology in Air Quality Control of SO_2", Coal Utilization Symposium -- Focus on SO_2 Emission Control, Louisville, Kentucky, October, 1974

AMAX Henderson, "An Experiment in Ecology", Editorial Alert - 1974, Mountain Empire Publishing Company

American Public Health Association, American Water Works Association & Water Pollution Control Federation, "Standard Methods for the Examination of Water and Wastewater" (13th Ed.), APHA, Washington, D.C., 1971

American Society for Testing Materials, "Standard Methods for (1) Collection of a Gross Sample of Coal, (2) Preparing Coal Samples for Analysis", Part 19

Anderson, J.C., "Coal Waste Disposal to Eliminate Tailings Ponds", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Atwood, Genevieve, "The Technical and Economic Feasibility of Underground Disposal Systems", Coal and Environmental Technical Conference, October 1974

Atwood, Genevieve, "The Technical and Economic Feasibility of Underground Disposal Systems", First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 1974

Balzer, J.L.; Urouch, D.B.; Poyser, R.W.; Sowards, W., "A Venture Into Reclamation", American Mining Congress Convention, October 1974

Barnes, H.L. & Romberger, S.B., "Chemical Aspects of Acid Mine Drainage", Western Research Application Center, University of Southern California, #CA-67

Battelle-Columbus, "SO_2 Control: Low-Sulfur Coal Still the Best Way", Power Engineering, November 1973

Bechtel, Inc., "Coal Slurry Pipeline--An Environmental Answer", San Francisco, California

Benza, Stephen T. & Lyon, Anne E., "The Use of Lime, Limestone and Other Carbonate Material in the New Coal Era", NCA/BCR Coal Conference and Expo II, October 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Bisselle, C.A.; Haus, S.A.; Lubore, S.H.; School, M.M.; & Wilcox, S.L., "Strategic Environmental Assessment System: Initial Analysis of Environmental Residuals", The Mitre Corporation, February 1973

Bituminous Coal Research, Inc., "Glossary - Surface Mining & Reclamation Technology", October 1974

Black Sivalls & Bryson, Inc., "Study of Sulfur Recovery from Coal Refuse", U.S. Government Printing Office, September 1971

Bluck, W.V. & Norton, G., "High Intensity Fine Coal Flotation", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Bioko, V.A. Parinskiy, O.P., "Equipment for Dewatering of Coal", Chapter 5 of "Hydraulic Capability for Underground Mining of Coal", Katalog-Spravochnik, Moscow, 1965 (Translated by Terraspace)

Bowen, James B. & Guiliani, R.L., "The Integrated Occupational Health Program of the Erie Mining Company", American Mining Congress Convention, Las Vegas, Nevada, October 1974

Brawner, C.O.; Pentz, D.L.; Campbell, D.B., "Ground Stability in Surface Coal Mines", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Brundage, R. Scott, "Depth of Soil Covering Refuse (GOB) vs Quality of Vegetation", Coal and the Environment Technical Conference, October 1974

Bureau of Water Quality Management, "Air and Water Quality Regulations"

Busch, Richard A.; Backer, Ronald R.; Atkins, Lynn A., "Physical Property Data on Coal Waste Embankment Materials", U.S. Bureau of Mines RI 7964, 1974

Capp, John P.; Gillmore, D.W.; Simpson, David G., "Coal Waste Stabilization by Enhanced Water", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Cassady, Jon M., "Obstacle Course for Permits and Approval", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Chedgy, David G., "Reduction of Environmental Noise Levels at the Meadow River No. 1 Preparation Plant", American Mining Congress Coal Show, Detroit, Michigan, May 1976

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Chemical Construction Corporation, "The High Sulfur Combustor - A Study of Systems for Coal Refuse Processing", New York, New York, February 1971

Chironis, Nicholas P., "Results of a Noise Control Program at a New Coal Preparation Plant", Coal Age, January 1976

Coal Research Bureau, "Underground Coal Mining Methods to Abate Water Pollution", West Virginia University, 1970

Consolidation Coal Company, "Conveying a Slurry Through a Pipeline", British Patent #861-537, February 1961

Cooper, Donal K., "Choosing Closed Circuits for Coal Preparation Plants", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Corp, Ernest L.; Schuster, Robert L.; McDonald, Michael W., "Elastic-Plastic Stability Analysis of Mine-Waste Embankments", U.S. Bureau of Mines RI 8069

Culp-Culp, "Advanced Waste Water Treatment", Van Norsten, 1971

Cutler, Stanley, "Emissions from Coal-Fired Power Plants", U.S. Department of Health, Education and Welfare, 1976

Dahlstron, D.A.; Silverblatt, C.E., "Dewatering of Pipeline Coal", U.S.A., Australian Coal Conference

Danielson, John A. (Editor), "Air Pollution Engineering Manual (2d Ed.)", U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, 1973

D'Appolonia, E., "Engineering Criteria for Coal Waste Disposal", Mining Congress Journal, October 1973

Day, James M., "Current Status of Proposed Federal Waste Disposal Rules", Mining Congress Journal, June 1974

Dean, K.C.; Havens, Richard; Blantz, M.W., "Methods and Costs for Stabilizing Fine-Sized Mineral Wastes", ULSL Bureau of Mines RI 7896 1974

Dean, Karl, C.; Havens, Richard, "Methods and Costs for Stabilizing Tailings Ponds", Mining Congress Journal, December 1973

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Decker, Howard; Hoffman, J., "Coal Preparation, Volume I & II", Pennsylvania State University, 1963

Decker, Howard W., Jr.; Hoffman, John N., "Dedusting, Dust Collection and Coal Surface Treatment (Chapter E)", Coal Preparation, Volume II, Pennsylvania State University, 1963

Department of Environmental Resources, "Solid Waste Management", State of Pennsylvania

Department of Environmental Resources, "Waste Water Treatment Requirements"; "Industrial Wastes"; "Special Water Pollution Regulations"; "Erosion Control", State of Pennsylvania

Department of Environmental Resources, "Water Quality Criteria", State of Pennsylvania

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Division of American Society Civil Engineering, "Journal of Sanitary Engineering"

Dokunin, A.V.; Onika, D.G., "Hydraulic Underground Mining", Translated for Branch of Bituminous Coal Research, Division of Bituminous Coal, U.S. Bureau of Mines

Doyle, Frank J.; Bhatt, H.G.; Rapp, J.R., "Analysis of Pollution Control Costs", Report prepared for Appalachian Regional Commission and Office of Research and Development of the EPA, EPA 670/2-74-009 February 1974

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Analysis of Pollution Control Costs", EPA 670/2-74-009

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Chemistry & Classification of Mine Drainage", EPA 670/2-74-009

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "National Ambient Air Quality Standards", EPA 670/2-74-009, February 1974

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Other Mine Drainage Abatement Procedures", EPA 670/2-74-009, February 1974

REFERENCES AND/OR ADDITONAL READING
(Continued)

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Refuse Bank & Mine Fires", EPA 670/2-74-009, February 1974

Dunnigan, A.R.; Dennis, R.A., "Control System for a Very Wide Range pH Effluent Stream"

Durard, John, "Permissible Noise Exposure--Walhealey Tables"

Ellison, Ricahrd D.; Almes, Richard G., "Synopsis of Engineering and Design Manual for Coal Refuse Embankments ", Coal and the Environment Technical Conference, October 1974

Ellison, William; Heden, Stanley D.; Kominek, Edward G., "System Reliability and Environmental Impact of SO_2 Processes", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Enviro-Clear Co., Inc., "Coal Preparation Plant Clarifier-Thickener", Bulletin C/11/74, New York City

Environmental Analysis, Inc., "Air Quality in Nassau-Suffolk County, N.Y.", 1972

Environmental Protection Agency, "Air Pollution Emission Factors", EPA Publication AP-72, April 1973

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Environmental Protection Agency, "Background Information for Standards of Performance: Coal Preparation Plants (Volume I: Proposed Standards)", Emission Standards & Engineering Division, EPA, Research, Triangle Park, North Carolina, October 1974

Environmental Protection Agency, "Background Information for Standards of Performance: Coal Preparation Plants (Volume II: Test Data Summary)", EPA, Research Triangle Park, North Carolina, October 1974

Environmental Protection Agency, "Environmental Impact Assessment Guidelines for Selected New Source Industries"

Environmental Protection Agency, "Municipal Sewage Treatment Standards

Fair, Geyer, and Okun, "Water and Waste Water Engineering", Vol. 2, Wiley and Sons, 1968

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Fairhurst, Charles, "European Practice in Underground Stowing of Waste from Active Coal Mines", First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 1974

Falkie, Thomas W., "Overview of Underground Refuse Disposal", First Symposium on Mine and Preparation Plant Refuse Disposal, Louisville, Kentucky, October 1974

Falkie, Thomas W., "Overview of Underground Refuse Disposal", Coal and the Environment Technical Conference, October 1975

Federal Register, "Mineral Resources - Rules and Regulations", Title 30, Chapter 1, Part 77

Federal Register, "Standards of Performance for New Stationary Sources (Coal Preparation Plants)", Volume 39, #207, Part II, EPA, October 24, 1974

Fletcher, J.R.; Schurtz, G.D., "Sulfuric Acid as a Soil Amendment to Enhance Plant Growth", American Mining Congress Convention, October 1974

Fomenko, T.G.; Kondratenko, A.F.; Perlifonov, A.G., "Thickening of Flotation Tailings in a Thickener with a Sludge Packer", UGOL #1, 1973

Foreman, William E.; Lucas, J. Richard, "Current Status of Hydrocyclone Technology", Mining Congress Journal, December 1972

Foreman, William E., "Impact of Higher Ecological Costs and Benefits on Surface Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Goodridge, Edward R., "Duquesne Light Maximizes Coal Recovery at its Warwick Plant", Coal Age, November 1974

Gospodarka, Gornictwa, "Possibilities of Mechanical Preparation Underground", 1956 No. 4

Gregory, M.J., "Problems Associated with Closing Plant Water Circuits", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Greenwald, Edward H., Jr., "A Landscape Architect Looks at Site Planning and Surface Development of Coal Mining", American Mining Congress Coal Show, Detroit, Michigan, May 1976

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Grim, E.C.; Hill, R.D., "Environmental Protection in Surface Mining of Coal", NERC, Cincinnati, Ohio, October 1974, EPA 670/2-74-093

Grimm, Bobby M., "Preparation Plant Corrosion Cost", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Gvozdek, G.; Macura, L., "Hydraulic Mining in Some Deep Pits in Czechoslovakia", Translated by National Coal Board (A 1683), Uhli #12, December 1958

Hill, Ronald D., "Water Pollution From Coal Mines", Water Pollution Control Association of Pennsylvania, 45th Annual Conference, 1973

Hoffman, L.; Truett, J.B.; Aresco, S.J., "An Interpretative Compilation of EPA Studies Related to Coal Quality & Cleanability", Mitre Corporation, May 1974, EPA 650/2-74-030

Hoyle, D.L., "The Effect of Process Design on pH & Pion Control", Eighteenth ISA-AID Symposium, May 3, 1972

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Province Coalfield", France, Australian Coal Conference

Ivanov, P.N.; Kotkin, A.M., "The Main Trends in Development of Beneficiation of Coal and Anthracite in the Ukraine", Ugol Ukrainy #2, February 1975 (Translated by Terraspace)

Journal of American Water Works Association

Joy Manufacturing Company, "Basic Handbook of Air Pollution Control Equipment", Western Participation Division, 1975

Kalb, G. William, "The Attainment of Particulate Emission Standards at Fluidized-Bed Thermal Coal Dryers", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Kalika, Peter W.; Bartlett, Paul T.; Kenson, Robert E.; Yocum, John E., "Measurement of Fugitive Emissions", 68th Annual APCA Meeting, Boston, Massachusetts, June 1975

Kenson, R.E.; Kalika, P. W.; Yocom, J.E., "Fugitive Emissions from Coal", NCA/BCR Coal Convention and Expo II, October 1975

Kent, James A. (Editor), "Riegel's Handbook of Industrial Chemistry (7th Ed.)", Van Nostrand Reinhild Publishing Company, New York, 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Keystone, "Coal Preparation Methods in Use at Mines", pp. 230-240

Kilgore, James D., "Physical and Chemical Coal Cleaning for Pollution Control", Industrial Environmental Research Laboratory, Environmental Protection Agency, Research Triangle Park, North Carolina

Knuth, William M., Jr.; Charbury, H. Beecher, "Remote Sensing Techniques for Analysis of Burning in Coal Refuse Banks", Coal and the Environment Technical Conference, October 1974

Koch Engineering Company, "Engineering Manual, Wet Scrubbing Systems for Air Pollution Control", Bulletin KPC2

Kodentsov, A.A.; Kurkin, V.F.; Krasnoyarskiy, L.S.; Papkov, M.N., "Dewatering of Coal and Rock, Clarification of Waste Water During Driving by Hydromechanization", Ugol Ukrainy #11 (Translated by Terraspace)

Kollodiy, K.K.; Borodulin, V.A.; Nazarov, P.G., "Processing of Coal Mined by the Hydraulic Method", Ugol #9, 1974 (Translated by Terraspace)

Korol, Dionizy, "Influence of Hydraulic Getting on Mechanical Coal Preparation", Przeglad Gorniczy, Year 12 #12, December 1956 (National Coal Board Translation Section)

Kosowski, Z.V., "Control of Mine Drainage from Coal Mine Mineral Wastes, Phase II - Pollution Abatement & Monitoring", EPA R2-73-230, May 1973

Krebs Engineers, "Brochure and Letter - June 1975"

Lamonica, J.A., "Noise Levels in Cleaning Plants", Mining Congress Journal, July 1972

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Leven, P., "Pumping: A Good Way to Dispose of Coal Plant Refuse", Coal Mining and Processing, June 1966

Lombardo, J.L., "State-of-the-Art--Acid Mine Drainage Control", American Mining Congress Mining Convention/Environmental Show, Denver, Colorado, September 1973

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Lotz, Charles, W., "Notes on the Cleaning of Bituminous Coal", School of Mines, West Virginia University, 1960

Lownie, H.W. et al., "A Systems Analysis Study of the Integrated Iron and Steel Industry", EPA Project PH-22-68-65 Report

Lowry, H.H. (Editor), "Chemistry of Coal Utilization", John Wiley & Sons, Inc., New York, New York, 1963

Luckie, Peter T.; Draeger, Ernie A., "The Very Special Considerations Involved in Thermal Drying of Western Region Coals", Coal Age, January 1976

Lusk, Ben E.; Piper, William L. (W. Va. Surface Mining and Reclamation Association), "Progress Report--Longwall Stripping", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Magnuson, Malcolm O., Baker, Eugene C., "State-of-the-Art in Extinguishing Refuse Pile Fires", Coal and the Environment Technical Conference, October 1974

Maneval, David R., "Assessment of Latest Technology in Coal Refuse Pile Fire Extinguishment", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Manwaring, L.G., "Coarse Coal Cleaning at Monterey No. 1 Preparation Plant", Mining Congress Journal, March 1972

Manzual, David R.; Lemezis, Sylvester, "Multistage Flash Evaporation Systems for the Purification of Acid Mine Drainage", SME/AIME Translations, Vol. 252

Margolf, Charles W., "Public Information--Industrial Involvement" American Mining Congress Coal Show, Detroit, Michigan, May 1976

Martin, John F., "Quality of Effluents from Coal Refuse Piles", Coal and the Environment Technical Conference, October 1974

Mathur, S.P., "Hydraulic Mining of Coal", Journal of Mines, Metals and Fuels, May 1972

McCormack, Donald E., "Soil Reconstruction: Selecting Materials for Surface Placement in Surface-Mine Reclamation", American Mining Congress Coal Show, Detroit, Michigan, May 1976

McGauey, "Engineering Management of Water Quality", McGraw-Hill, 1968

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Metcalf & Eddy Inc., "Waste Water Engineering, Collection-Treatment-Disposal", McGraw-Hill

Meyers, Sheldon, "The Development of Coal Resources and the Environmental Impact Statement", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Mill, Ronald, "Control & Prevention of Mine Drainage", Battelle Conference 72, November 1972

Miller, F.; Wilson, E.B., "Coal Dewatering - Some Technical and Economic Considerations", American Mining Congress Coal Convention, May 5-8, 1974

Mitchell, Donald W.; Murphy, Edwin M., "Case Study of Mine Sealants", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1976

Mooman, H.F.; Zachar, F.R.; Leonard, Joseph W., "Feasibility Study of a New Surface Mining Method, 'Longwall Stripping'", EPA 670/2-74-002, February 1974

Moss, E.A.; Akens, D.J., Jr., "Dewatering of Mine Drainage Sludge", EPA R2-73-169, February 1973

Moulton, Lyle K.; Anderson, David A.; Hussain, S.M.; Seals, Roger K., "Coal Mine Refuse: An Engineering Manual", Coal and the Environment Technical Conference, October 1974

Nalapko, I.A.; Shevchenko, I.A.; Manza, P.I., "Industrial Tests of a Plant Unit for the Extinction and Transportation of Slag and Ash"

Nalco Chemical Company, "Brochure and Letter - 1975"

Nalco Chemical Company, "Removal of Particulates from Gaseous Emissions", Oak Brook, Illinois, July 1974

National Coal Association, "National Ambient Air Quality Standards--Environmental Protection Agency"

National Coal Association, "First Symposium on Mine & Preparation Plant Refuse Disposal", Coal and the Environment Technical Conference, October 1974

National Coal Association, "Research and Applied Technology Symposium Mined-Land Reclamation", National Coal Association Convention, Pittsburgh, Pennsylvania, March 1973

REFERENCES AND/OR ADDITIONAL READING
(Continued)

National Coal Association, "Third Symposium on Surface Mining and Reclamation, Volume I", NCA/BCR Coal Conference and Expo II, October 1975

National Coal Association, "Third Symposium on Surface Mining and Reclamation, Volume II', NCA/BCR Coal Conference and Expo II, October 1975

National Coal Board, "Exploratory Trails in Hydraulic Mining at Trelewis Drift Mine", September 1961

National Coal Board, "Hydraulic Transport of Coal at Woodend Colliery", September 1961

Nirtsiyev, "Hydraulic Extraction of Coal in the Donetz Basin Izdatel 'Stvo "NEDRA", Moscow 1969 (Translated by Terraspace)

Nunenkamp, David C., "Survey of Coal Preparation Techniques for Hydraulically Mined Coal", Published for Terraspace Inc., July 1976

O'Brien, Brice, "Environmental Protection", Mining Congress Journal, February 1974

O'Brien, Ellis J.; Walker, Joseph L., "Environmental and Processing Innovations--Bullitt Preparation Plant", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1973

O'Brien Ellis J.; Sharpeta, Kenneth J., "Water-Only Cyclones; Their Functions and Performance", Coal Age, January 1976

Okhrimenko, V.A.; Kuprin, A.I.; Ishchuk, I.G., "Baring and Working Hydromine Fields (Chapter 2)", "Automation of Hydraulic Extraction (Chapter 11)", Moscow, 1974

Parkes, David M; Grimley, A.W.T., "Hydraulic Mining of Coal", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Patterson, Richard M., "Closed System Hydraulic Backfilling of Underground Voids", First Symposium on Mine and Preparation Plant Refuse Disposal, Coal and the Environment Technical Conference, October 1974

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

Peluso, Robert G., "A Federal View of the Coal Waste Disposal Problem", Mining Congress Journal, January 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Peterson, Gerald, "Noise Control in Coal Preparation Plants", Mining Congress Journal, January 1974

Phelan, J.E., "Applications of Wet Scrubber Additives", EPA & APT Symposium, San Diego, California, May 1974

Pollution Engineering Magazine, "Applying Air Pollution Control Equipment", Environmental Handbook Series

Pollution Engineering Magazine, "Industrial Solid Waste Disposal", Environmental Handbook Series

Poundstone,William, "Problems in Underground Disposal in Active Mines", First Symposium on Mine and Preparation Plant Refuse Disposal, Coal and the Environment Technical Conference, Lousville, Kentucky, October 1974

Powell, J.R.; Kopp, J.; Reich, M.; Steinberg, M., "Photodeformation Measurements of Refuse Pile Structure Movements", Coal and the Environment Technical Conference, October 1974

Pritchard, David T., "Closed Circuit Preparation Plants and Silt Ponds", Mining Congress Journal, November 1974

Protopapas, Panayotis, "A Report in Mineral Processing", Department of Applied Earth Sciences, Stanford University, 1973

Protsenko, I.A., "The Technology of Beneficiation and Dewatering of Coal Mined by the Hydraulic Method", Questions Regarding the Hydraulic Production of Coal, Trudy VNIIGidrougol, Vol. XI, 1967 (Translated by Terraspace)

Reiss, Irvin, "Surface Mining and Interim Land Use", American Mining Congress Convention, October 1974

Richardson, James K., "Improving the Public Image of the Mining Industry", American Mining Congress Convention, October 1974

Roberts & Schaefer Company, "Material Handling and Processing Facilities for the Mining Industry", 1974

Roberts & Schaefer Company, "Research Program for the Prototype Coal Cleaning Plant, January 1973

Rubin, E.S.; MacMichael, F.C., "Impact of Regulations on Coal Conversion Plants", Environmental Science & Technology, 9, 112, 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Sarkar, G.G.; Konar, B.B.; Sakha, S.; Sinha, A.K., "Demineralization of Coal by Oil-Agglomeration", Part I: Studies on the Applicability of the Oil-Agglomeration Technique to Various Coal Beneficiation Problems, India, Australian Coal Conference

Scott, R.B.; Hill, R.D.; Wilmoth, R.C., "Cost of Reclamation & Mine Drainage Abatement, Elkins Demonstration Project", Federal Water Quality Administration Publication #14010

Scott, Robert B., "Sealing of Coal Refuse Piles", Program Element 1B2040, NERC-USEPA, Cincinnati, Ohio, July, 1973

Seibel, Richard J., "Dust Control at a Transfer Point Using Foam and Water Sprays", U.S. Bureau of Mines Respirable Dust Program Technical Progress Report, May 1976

Shields, Donald H., "Innovations in Tailings Disposal", Coal and the Environment Technical Conference, October 1974

Sittig, Marshall, "Environmental Sources and Emissions Handbook", Data Corporation, Park Ridge, New Jersey, 1975

Skinderowicz, F., "Typical Technical Solutions of a Loading Point During Gravity Hydraulic Transportation of Coal", Wiadomosci Gornicza, Vol. 10 #3, 1959

Sorrell, Shawn T., "Establishing Vegetation on Acidic Coal Refuse Materials Without Use of a Topsoil Cover", Coal and the Environment Technical Conference, October 1974

Stanin, S. Anthony, "Influence of Coal Waste Disposal Regulations", American Mining Congress Coal Show, Detroit, Michigan, May 1976

Stefanko, Robert; Ramani, R.V.; Chopra, Ish Kumar, "The Influence of Mining Techniques on Size Consist and Washability Characteristics of Coal", National Technical Information Service, Springfield, Virginia, August 1973

Terchick, A.A.; King, D.T.; Anderson, J.C., "Application and Utilization of the Enviro-Clear Thickener in a U.S. Steel Coal Preparation Plant", Transactions of the SME, Volume 258, June 1975

Tyree, P.O.; Anderson, M.M., "Pilot Studies in Wet Dust Control", Mining Congress Journal, September 1973

Ungar, Fax, Patterson, Fox, "Coal Cleaning Plant Noise and Its Control", Bolt, Beranek, & Newman, Inc., U.S. Bureau of Mines Contract No. H0133027

REFERENCES AND/OR ADDITIONAL READING
(Continued)

U.S. Bureau of Mines, "Implications of the Water Pollution Control Act of 1972 for the Mineral Resource Industry: A Survey", Interdisciplinary Research Task Force Committee, 1975

U.S.S.R., "Intensification of Coal Slurries Treatment and Dewatering Processes", Australian Coal Conference

Verschuur, E.; Davis, G.R., "The Shell Pelletizing Separator: Key to a Novel Process for Dewatering and De-Ashing Slurries of Coal Fines", Holland, Australian Coal Conference

Wahler, William A., "Coal Refuse Regulations, Standards, Criteria and Guidelines", Coal and the Environment Technical Conference, October 1974

Wahlquist, Brent T., "Developing Strip Mine Reclamation Plans", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

W. A. Wahler & Associates, "Analysis of Coal Refuse Dam Failure--Volume I", National Technical Information Service, Springfield, Virginia, February 1973

W. A. Wahler & Associates, "Analysis of Coal Refuse Dam Failure--Volume II", National Technical Information Service, Springfield, Virginia, February 1973

W. A. Wahler & Associates, "Coal Mine Refuse Disposal Practice and Technology", U.S. Bureau of Mines Contract No. SO 122084, February 1974

W.A. Wahler & Associates, "Evaluation of Mill Trailings Disposal Practices and Potential Dam Stability Problems in the Southwestern United States", U.S. Bureau of Mines Contract No. SO 110520

Warnke, W.E., "Latest Progress in Sulfur, Moisture and Ash Reduction Coal Preparation Technology", American Mining Congress Coal Convention, Detroit, Michigan, May 1976

Weber, Walter J., Jr., "Physiochemical Processes for Water Quality Control", Wiley Interscience, Division of John Wiley & Sons, Inc., New York, 1972

Wei-Tseng Peng, "The Jet-Cyclo Flotation Cell", The People's Republic of China, Australian Coal Conference

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Wemco Division, "Manufacturer's Catalog", Envirotech Corporation, Sacramento, California, 1974

Williams, Cyril H., Jr., "Planning, Financing and Installing a New Deep Mine in the Beckley Coal Bed", Mining Congress Journal, August 1974

Yancey, J.F.; Geer, M.R., "Behavior of Clays Associated with Low-Rank Coals in Coal-Cleaning Processes", U.S. Bureau of Mines Report of Investigations #5961

Yancey, J.F., "Determination of Shapes of Particles in Coal and Their Influence on Treatment of Coal by Tables", AIME Translation, 94

Yancik, Joseph H., "Research to Improve Coal Mining Productivity", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1976

Yusa, M.; Suzuki, H.; Tanaka, S.; Igarashi, C., "Sludge Treatment Using A New Dehydrator", Japan, Australian Coal Conference

14. REMOVAL OF CONTAMINANTS FROM COAL

14.1 OVERVIEW

The combustion of coal results in the formation of pollutants which include oxides of sulfur and nitrogen, plus the elemental forms or compounds of beryllium, chlorine, fluorine, arsenic, selenium, cadmium, mercury, lead and other potential pollutants. Sulfur oxide, nitrogen oxide and particulate air pollution emissions from coal combustion exceeded 28 million metric tons in 1974.

Sulfur dioxide (SO_2) is the pollutant of principal concern. Annual SO_2 emissions from coal combustion in 1974 were estimated to be 20.5 million tons. This represents 65% of the total SO_2 emissions for that year. On a national basis the 5.3 million tons of NO_x emissions from coal combustion represented 24% of the total 1974 NO_x emissions. Emissions of other potentially hazardous elements or compounds while not as large may present environmental or health problems because of their concentration in process waste streams, concentration in the environment or effects produced by prolonged exposure at low concentrations. Coal-fired electric utility plants are the major source of sulfur oxide air pollution in the United States today. In 1974 the electric utilities burned 390 million tons of coal with an average sulfur content of 2.2 percent. The amount of coal consumed by electric utilities is anticipated to reach 500 million tons by 1980 and approximately a billion tons by the year 2000. It is therefore imperative that sulfur oxide emissions be controlled.

Only 14% of the 455 U. S. coals tested for physical cleanability by the U. S. Bureau of Mines are capable of meeting federal new source performance standards (NSPS) for steam generators (1.2 lb $SO_2/10^6$ Btu) as mined. Available methods for controlling sulfur oxide emissions from stationary combustion sources fall into the following major categories:

- The physical removal (coal cleaning) of pyritic sulfur prior to combustion.
- The removal of sulfur oxides from the combustion flue gas.
- Conversion of coal to a clean fuel by such processes as gasification, liquefaction and chemical extraction.

Physical and chemical coal cleaning processes are capable of removing major quantities of pollution species (especially sulfur) prior to coal combustion. As discussed in Chapter 2, sulfur exists in coal in two principal forms: organic sulfur, which is bonded to the coal structure, and inorganic sulfur, generally in the form of pyrite. U. S. coals vary widely in the relative amounts of organic and pyritic sulfur. Physical coal cleaning with equipment normally used for removal of ash and mining residues is capable of separating coal and pyritic sulfur. Chemical cleaning is capable of removing both pyritic and organic sulfur.

Of the 455 U. S. coals tested for cleanability by the U. S. Bureau of Mines, it has been estimated that for a 1½ inch top size feed if physically cleaned to a 90% Btu recovery, 24% could meet NSPS. Physically cleaned at the same top size and to the same Btu recovery, 35% are capable of meeting a standard of 2.0 lb $SO_2/10^6$ Btu, while over 60% are capable of meeting a standard of 4.0 lb $SO_2/10^6$ Btu. Many states have emission standards as high as 4.0 lb $SO_2/10^6$ Btu. Thus, there may be a significant application of physical coal cleaning to meeting state emission regulations.

Chemical coal cleaning is capable of higher levels of desulfurization. Thus it potentially has a wider range of applicability. In some instances, depending upon the coal, the emission regulation and site specific considerations, it may be the most cost effective method for SO_2 emission control. However, for other cases, chemical coal cleaning may not be competitive with either physical cleaning or flue gas desulfurization. Figure 14-1 presents the ranges of estimated costs and the degree of applicability for different sulfur emission control strategies. As indicated, of these three methods the physical removal of pyritic sulfur is potentially the lowest cost and certainly the most developed method technologically. However, as stated in Chapter 2, the amount of total sulfur reduction that may be obtained by physical methods is limited to that quantity of the total sulfur content that is not chemically bonded to the coal; i.e., the pyrite and sulfate sulfur. Organic sulfur comprises from 30 to 70% of the total sulfur of most coals. Sulfate sulfur content is usually less than 0.05% and it is an oxidation product that is readily removed during physical coal cleaning.

As discussed in detail in Chapter 7, the techniques now widely used on a commerical basis for the removal of these impurities include jigging, heavy media separation, water-only cyclones, tabling and flotation. These methods depend upon differences in physical and chemical properties of the coal and impurities to achieve separation. Since

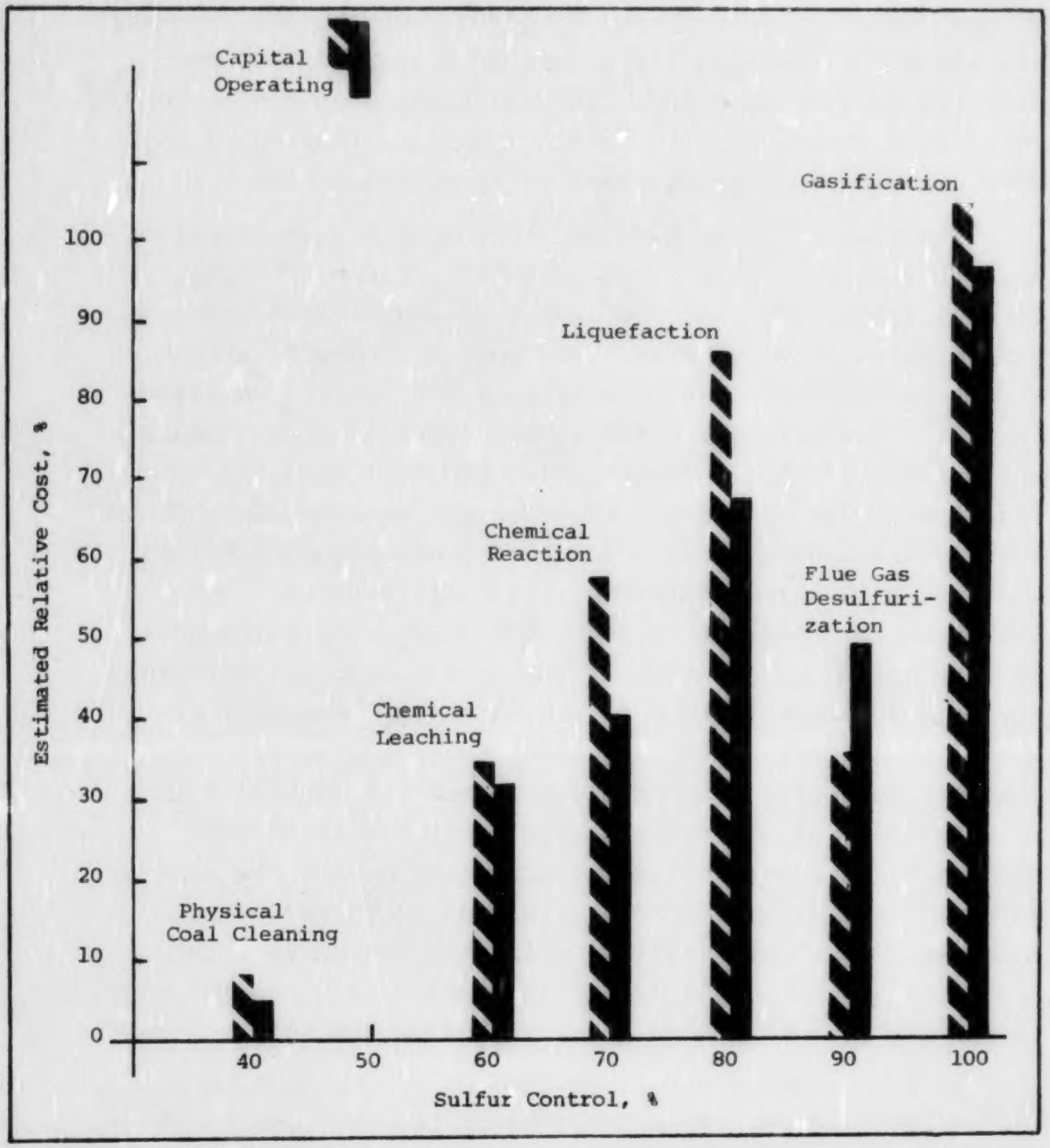


Figure 14-1

Estimated Costs of Sulfur Removal
Potential of Different Emission Control Strategies

1965 the EPA, the U. S. Bureau of Mines, the Bituminous Coal Research, Inc. and others have cooperatively evaluated these and other techniques for the selective removal of pyrite from coal. Some of the "other" techniques evaluated have included thermal-magnetic separation, immiscible liquid separation, selective flocculation, electrokinetic separation and two-stage froth flotation. Techniques which rely upon differences in specific gravities of the coal and pyrite particles have been found to be the most commercially viable for desulfurization. Froth flotation which depends upon the selective adhesion of air bubbles to the coal particles has also been found to be a useful commercial technique.

Because some coals are more amenable than others to sulfur removal by physical methods, studies have been performed on U. S. coals to determine pyrite liberation by size reduction and separation by specific gravity differentials. The 455 samples tested to date are from mines which provide more than 70% of the coal used in U. S. utility boilers. The laboratory float-sink tests performed in organic liquids of specific gravities ranging from 1.3 to 1.9 and size fractions from a minus 1½ inches to a minus 14 mesh provide information on the pyritic sulfur which can be removed from these coals.

The results of these float-sink or washability studies indicate that the pyritic sulfur removal generally increases with reduced coal particle sizes and specific gravities. Crushing to finer sizes liberates more of the dense mineral matter from the coal matrix and low media specific gravities allow more of this dense material to sink. At low specific gravities a cleaner product is obtained; i.e., ash ash and pyritic sulfur are decreased. However, this clean product is obtained at reduced Btu recovery.

Theoretically at very fine sizes a large percentage of the pyritic sulfur could be released from the coal matrix and separated without excessive Btu losses. This fact is extremely important. It implies that to enhance sulfur removal more of the coal must be crushed and processed at finer sizes than historically practiced in coal preparation. This will require modifications to current processing plant design practices. These design changes will necessarily incorporate techniques for improved fine coal separation, dewatering and drying. Modified pollution control and waste disposal techniques will also be required.

Table 14-1 presents data on the amount of pyritic sulfur which can be removed from coal samples from six regions by crushing to a top size of 3/8 inch and by separation at a specific gravity of 1.6. It is important to note that the pollutant potentials of the cleaned coals represented by the data in column 5 are significantly different. (The term "pollutant potential" is used since it is assumed that all the sulfur contained in the cleaned coal is converted and emitted as SO_2.) For example the average SO_2 pollutant potential for the Northern Appalachian, the Southern Appalachian and the Eastern Midwest coal region samples are 2.7, 1.3 and 4.2 lb $SO_2/10^6$ Btu, respectively.

14.2 WASHABILITY STUDIES

A washability analysis is an evaluation of those physical properties of a coal which determine its amenability to improvements in quality by cleaning. This includes stage crushing to release impurities and specific gravity fractionation to show the quality and quantity of the cleaned product. A washability study is made by testing the coal sample at preselected, carefully controlled specific gravities. This is termed "float-sink" analysis

Table 14-1
Summary of the Physical Desulfurization Potential of Coals by Region[a]

Cumulative Analyses of Float 1.60 Product

		Percent						
Region	No. of Samples	Btu Recovery	Ash	Pyritic Sulfur	Total Sulfur	Pounds $SO_2/10^6$ Btu[b]	Calorific Content, Btu per Pound[c]	SO_2 Removal Efficiency Required for NSPS[d] in Percent
Northern Appalachian	227	92.5	8.0	0.85	1.86	2.7	13,766	56
Southern Appalachian	35	96.1	5.1	0.19	0.91	1.3	14,197	8
Alabama	10	96.4	5.8	0.49	1.16	1.7	14,264	29
Eastern Midwest	95	94.9	7.5	1.03	2.74	4.2	13,138	71
Western Midwest	44	91.7	8.3	1.80	3.59	5.5	13,209	78
Western	44	97.6	6.3	0.10	0.56	0.9	12,779	None
U.S. Total	455	93.8	7.5	0.85	2.00	3.0	13,530	60

[a] Summary of the composite product analyses for 3/8 inch top size, float-sink tested at 1.6 specific gravity.

[b] Based upon the moisture free Btu value of the float coal and assuming all sulfur is converted to SO_2. Actual emissions will vary depending on the as-fired coal moisture content and the conversion efficiency of sulfur to SO_2.

[c] Moisture free basis.

[d] Values may require adjustment to account for the as-fired coal moisture content and efficiency of sulfur conversion to SO_2. NSPS - Federal New Source Performance Standards for Steam Generators (1.2 lb $SO_2/10^6$ Btu).

Source: U.S.B.M. RI 8118 as modified by James Kilgroe USEPA in a paper entitled "Physical and Chemical Coal Cleaning for Pollution Control" or specific gravity separation. Mixtures of organic liquids are commonly used to obtain the desired specific gravities of separation. Chemical analyses of the various specific gravity fractions of the coal are used to compile the washability data which indicate how well the coal can be prepared.

14.2.1 Description of Testing Procedures (Float and Sink Analysis)

The following information is quoted exactly or paraphrased from the U. S. Bureau of Mines RI 8118 by J. A. Cavallaro, M. J. Johnston and A. W. Deurbrouck as published in 1976.

Collection of Samples

> Face samples were collected from surface and deep mines which were producing coal primarily for consumption by electric utilities. In general, an attempt was made to sample the largest utility coal producing mines in the United States; therefore, the 455 coal mine samples reported in this publication represent mines which provide more than 70 percent of the annual utility coal production.
>
> Face samples were collected according to the procedure recommended by Fieldner and Selvig[1] and Holmes[2], except that the dimensions of each sample cut were expanded to permit 600 pounds of coal to be taken from the face. Partings and impurities were not removed from the samples unless otherwise noted. The face was cleared of loose coal or dirt for a width of approximately 5 feet. Loose pieces of roof were also taken down to prevent their falling into the sample while it was being obtained. Within the

---

[1] Fieldner, A.C. & W.A. Selvig. Notes in the Sampling and Analysis of Coal. Bureau of Mines Technical Paper 586, 1938, 48 pp.

[2] Holmes, J. A. The Sampling of Coal in the Mine. Bureau of Mines Technical Paper 1, 1918, 22 pp.

cleaned off area on the face, the coal was cut from the roof to the floor in a channel one inch deep and about 3 feet wide to remove any altered or otherwise inferior coal. The floor was then cleared and smoothed and a sampling cloth was spread prior to collecting the sample.

The actual channel sample was cut perpendicular to the lay of the coalbed, approximately 10 inches deep and wide enough to provide a sample of 600 pounds. For example, for a 4-foot-thick coalbed a channel 30.5 inches wide would be collected. The exception to this rule would be when a strip mine sample is obtained where the overburden has been removed. In this case, the depth and width of the channel would be equal. For example, for the 4-foot-thick bed noted above, the channel would be 17.5 inches deep by 17.5 inches wide. The collected sample includes all partings and other impurities occurring in the channel.

Sample Preparation

The 600 pound channel samples collected in the field are loaded into steel drums and returned to the coal preparation laboratory for processing. The sample preparation procedure is outlined in the flowsheet shown in Figure 14-2. Each sample to be tested is air dried and then crushed to 1½ inch top size using a single roll crusher. The sample is then coned, long piled and shoveled into four pans, according to ASTM specifications, and divided into two portions by combining opposite pans.

One of the 1½ inch by 0 portions is processed as is; the other portion is crushed in a jaw mill to 3/8 inch top size. This 3/8 inch by 0 material is then riffled into two portions; one is processed as is (3/8 inch by 0) and the other is crushed to 14-mesh top size in a hammer mill and processed.

A head sample is riffled from the 14-mesh by 0 portion for proximate analysis (moisture, ash, volatile matter and fixed carbon) and for determination of calorific value, fusibility of ash, free-swelling index, Hardgrove grindability index and sulfur forms and content (pyritic, organic and total). Since the minus 100-mesh material represents such a small percentage of the weight of the two coarser size fractions analyzed, it is removed prior to float-sink testing and is not presented in this report.

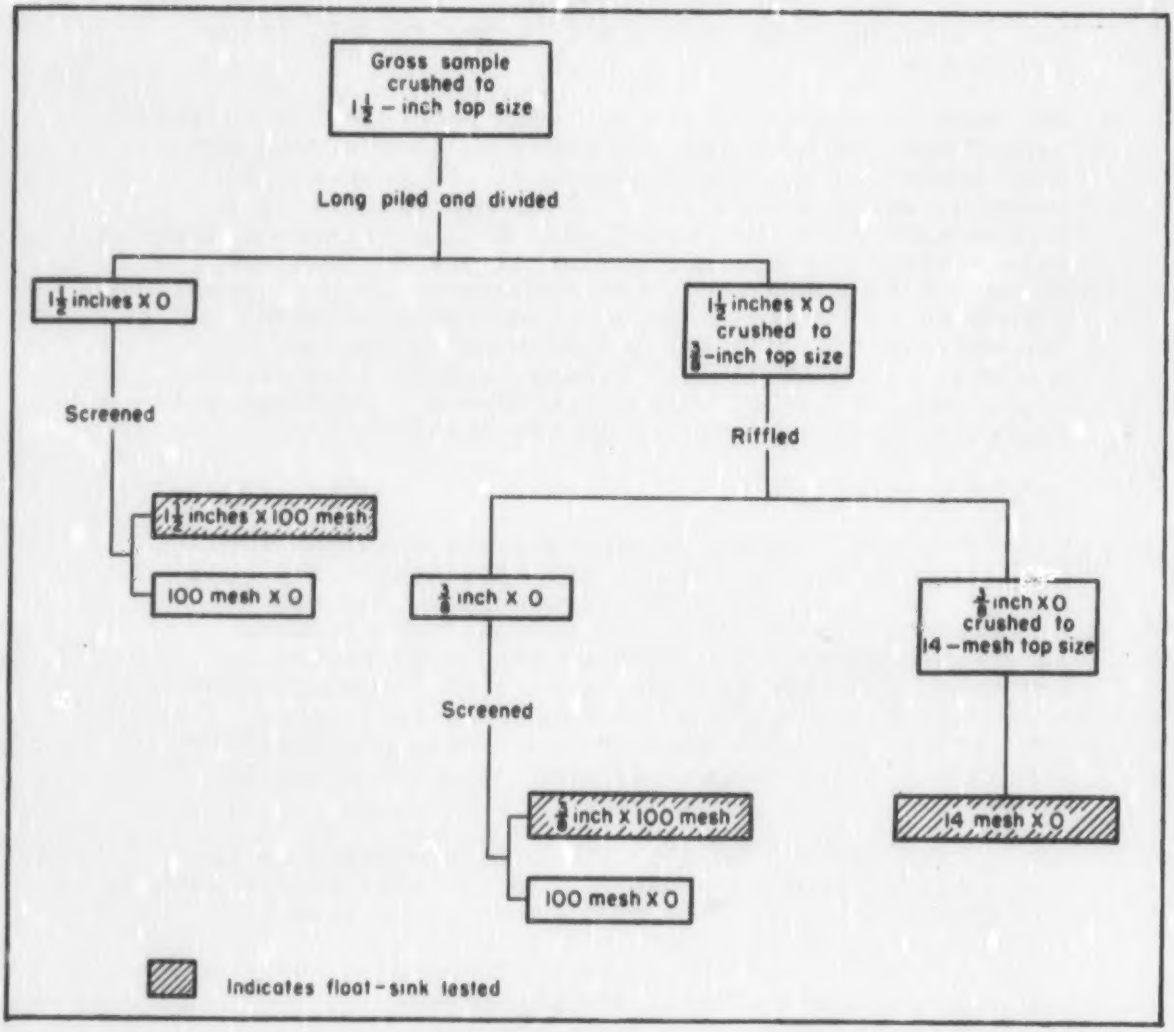

Gross sample crushed to 1½-inch top size
Long piled and divided
1½ inches X 0
1½ inches X 0 crushed to ⅜-inch top size
Screened
Riffled
1½ inches X 100 mesh
100 mesh X 0
⅜ inch X 0
⅜ inch X 0 crushed to 14-mesh top size
Screened
⅜ inch X 100 mesh
14 mesh X 0
100 mesh X 0
Indicates float-sink tested

Figure 14-2

Flow Diagram Showing Preparation of Face Samples

Source: U. S. Bureau of Mines RI 8118

> The various sized fractions are then float-sink tested at 1.30, 1.40 and 1.60 specific gravities using CERTIGRAV, a commercial organic liquid of standardized specific gravity; the solution tolerance is ±0.001 specific gravity unit and is monitored using a spindle hydrometer. Those samples processed by Commercial Testing and Engineering Co. were further float-sink tested at 1.90 specific gravity.

The principle of float and sink testing procedure is as follows: weighted amounts of the different size fractions are added gradually and in small quantities to the liquid of the lowest gravity. The total fraction which floats is separated from the fraction which sinks. The liquid absorbed by the coal is eliminated, if necessary, and the procedure is repeated successively with liquids extending over the desired range of specific gravities. The fraction which sinks in the liquid of highest specific gravity is also obtained. The weight and ash content of each fraction are determined. The results are expressed as percentages of the size fraction treated and are calculated also as weighted percentages of the total sample treated, excluding the dust. The results are usually set out graphically in a series of curves.

> For the two coarser sizes, the separation is made in a screen bottom container which is inserted in 10 gallon capacity vessels containing the organic liquid. The sample is placed in the 1.30 specific gravity bath, in small quantities to prevent entrapment, and is then stirred and allowed to separate. The lighter specific gravity coal fraction is removed from the surface of the bath with a screen wire strainer; the heavier specific gravity material settles to the container bottom which is then raised above the liquid level to drain. The container with the heavier specific gravity material is then placed in the 1.40 specific gravity solution and the process is repeated. This is continued until the sample is separated into the desired specific gravity fractions.
>
> For the 14-mesh by 0 size fraction, the separation is made in glass separatory flasks joined by standard ground taper joints. After the sample separates, a

stopper is passed through the float layer and inserted into the neck of the separatory funnel. Both products are filtered; the "floats" are dried and prepared for analysis, while the "sinks" are reintroduced into another separatory flask containing a heavier specific gravity liquid and the float-sink procedure is continued.

Upon completion of the float-sink testing, the specific gravity fractions of the three sized samples are analyzed for ash, pyritic sulfur and total sulfur content. All chemical analyses are reported on a moisture-free basis unless otherwise noted. Raw coal moisture, as presented in the appendix tables, is the moisture contained in the sample after being air dried at the coal preparation laboratory. The air dry loss is not included in the moisture determination. It is felt that under normal conditions the moisture content as reported here would closely simulate the moisture content of the coal burned at the power plant. Specific gravity separations of fine coal are particularly difficult, especially with coals that are porous and contain high inherent moisture contents, because the heavy liquid used can penetrate the pores and increase the apparent specific gravity of the coal. This explains the unexpectedly low weight recoveries noted occasionally for the float 1.30 specific gravity fraction of the lower rank coal samples crushed to 14-mesh top size.

The float-sink data from the channel samples are not to be construed as representing the quality of the product loaded at the mine where the sample was taken, but rather as indicating the quality of the bed in that particular geographical location. Float-sink data are based upon theoretically perfect specific gravity separations that are approached but not equalled in commercial practice.

14.2.2 Description of Testing Procedures (Total Sulfur and Form of Sulfur)

The total sulfur content in a sample of coal may be determined by any one of three methods according to ASTM Testing Procedure D 3177-75. The procedures appear in the following order:

- Eschka method
- Bomb washing method
- High-temperature combustion method.

The Eschka method consists of incinerating coal and coke with Eschka mixture (2 parts of light calcined magnesium oxide (MgO) and one part of anhydrous sodium carbonate (Na_2CO_3). After allowing the contents to cool, the contents are thoroughly washed with hot water; a small quantity of hydraulic acid is added to make the washed solution slightly acid and the sulfur is precipitated out by the addition of a hot 10-percent solution of barium chloride ($BaCl_22H_20$). After cooling and washing, the filtered precipitate is ashed and weighed. The sulfur content is calculated as follows:

Sulfur percent in the analysis sample equals:

$$\frac{(A-B) \times 13.738}{C},$$

where:

A = grams of $BaSO_4$ precipitated,
B = grams of $BaSO_4$ correction and
C = grams of sample used.

Total sulfur may also be determined in the washings from the oxygen bomb calorimeter after the calorimetric determination. The U. S. Bureau of Mines has found that the results from this method check closely with those of the Eschka method. In addition, the bomb-washing methods save considerable time over the Eschka method and is therefore primarily used by the U. S. Bureau of Mines Coal Analysis Laboratory. In this technique, the bomb is fired, cooled and depressurized as specified. After washing with distilled water and methyl orange until no acid reaction is observed, the washings are collected and titrated with standard ammonia solution to obtain the acid correction for the heating value. After boiling, washing and filtering the resulting solution, hydrochloric acid is added and the heated solution is precipitated with barium chloride as described for the Eschka method. Again the sulfur content is calculable by the formula:

$$\frac{(\text{Weight of } BaSO_4 - \text{blank}) \times 13.74}{\text{Weight of sample}} =$$

Percentage of Sulfur

Permissible difference of the same sample, same laboratory follow:

Ultimate Analysis of Sulfur, percent	Permissible differences, percent	
	Eschka Method	Bomb-Washing Method
0 - 2	0.05	0.10
2 - 4	.08	.15
Over 4	.10	.20

In the high-temperature combustion method, a weighed sample of coal is burned in a tube furnace at a temperature of 1350° C. in a stream of oxygen. The sulfur oxides and chlorine formed are absorbed in a hydrogen peroxide (H_2O_2) solution yielding hydrochloric (HCl) and sulfuric (H_2SO_4) acids. The total acid content is determined by titration with sodium hydroxide (NaOH), and the amount of sodium chloride (NaCl) resulting from the titration of the HCl is converted to NaOH with a solution of mercuric oxycyanide (Hg(OH)CN). This sodium hydroxide is determined titrimetically and used to correct the sulfur value which is equivalent to the amount of H_2SO_4 formed during the combustion of the coal. The percent of sulfur is calculable as follows:

$$S = \frac{1.603\ (F_1(a-a_1) - F_2(b-b_1)}{W}$$

where:

S = percent sulfur in coal.

a = millilitre of NaOH solution used in full determination.

a_1 = millilitre of NaOH solution used in blank determination.

b = millilitre of H_2SO_4 in full determination.

b_1 = millilitre of H_2SO_4 in blank determination.

F_1 = normality of NaOH solution.

F_2 = normality of H_2SO_4 solution.

W = grams of coal taken.

After the total sulfur content in a particular coal sample has been determined, the three commonly recognized forms of sulfur in coal (sulfate sulfur, pyritic sulfur and organic sulfur) may be determined as defined in ASTM Designation: D 2492-68 (reapproved 1975).

The sulfate sulfur is determined by extracting a weighed sample of coal with dilute hydrochloric acid followed by precipitation with barium chloride ($BaCl_2$) and weighing as barium sulfate. The sulfate sulfur is soluble in dilute hydrochloric acid; pyritic and organic sulfur are not. This procedure is summarized in U. S. Bureau of Mines Bulletin "Methods of Analyzing and Testing Coal and Coke":

> "Weigh out a 2.0000-gram sample, weighed to 0.1 mg, and place it in a 250-ml beaker. Add 3 ml of 1:3 ethyl alcohol and swirl to wet the sample. Cover the sample carefully with 50 ml of hydrochloric acid (1:3). Cover with a watch glass and place on a hotplate to boil.

> At the end of 20 minutes, filter the contents of the beaker, retaining the coal material left on the filter, after washing six times with cold water, for the pyritic sulfur determination. To the filtrate add 10 ml of bromine water and heat almost to boiling. Add 20 to 25 ml of 1:1 ammonium hydroxide, and let stand on a hotplate for 20 minutes. Filter while hot, discarding the residue left on the filter after washing five or six times with hot water. Increase the volume of the filtrate to 200 ml with distilled water.
>
> Neutralize the filtrate with hydrochloric acid (2:1) and add an excess of 5 ml, using methyl orange indicator. Heat the solution to boiling, add slowly 20 ml of hot 10 percent barium chloride solution, and allow to stand for several hours. Filter and wash the precipitate with hot water until free of chlorides, ignite the filter paper, and weigh the barium sulfate. The weight of barium sulfate, in grams, multiplied by 6.868 represents the percentage of sulfur combined as sulfate in the coal."

Pyritic sulfur is determined by extracting a weighed sample of coal with dilute nitric acid followed by titrimetric determination of iron in the extract as a measure of pyritic sulfur. The extraction process with the use of nitric acid involves oxidation of ferrous iron to ferric and sulfide sulfur to sulfate, both of which are soluble in nitric acid. Because the extraction dissolves sulfate and pyritic sulfur plus a small amount of organic sulfur, the dissolved sulfur is not a reliable measure of pyritic sulfur. Consequently, pyritic sulfur is obtained by determining the amount of iron combined in the pyritic form which is equal to the difference between nitric acid and hydrochloric acid-solution iron.

The sample of coal used for the pyritic sulfur determination may be a separately weighed sample or the residue from the hydrochloric acid extraction for sulfate sulfur. If the residue is used, two acid extractions are carried out on the same sample, the nitric acid treatment being applied to the coal residue from the hydrochloric acid extraction for determination of sulfate sulfur. Determination of iron in the hydrochloric acid extract is unnecessary, because iron in the nitric acid extract represents pyritic iron. However, there are certain limitations to the use of sulfate sulfur residue for determination of pyritic sulfur in coal: if pyritic iron is high, the large sample required for determination of small amounts of sulfate sulfur will contain large quantities of iron and may require dilution; the determination of pyritic iron cannot be carried out until both extractions of sulfur have been completed. According to U. S. Bureau of Mines testing procedures for pyritic sulfur(Bulletin 538 USBM Office of Coal Research 1967):

> "Macerate the coal residue and filter paper from the hydrochloric acid separation in 100 ml of 25 percent by volume nitric acid and allow to stand, with occasional stirring for 12 to 24 hours at room temperature. Filter and discard the coal residue after washing several times with cold water. Add 3 ml of concentrated hyrdochloric acid to the filtrate and evaporate to dryness on a water bath. Dissolve the residue in 5 ml of concentrated hydrochloric acid and 25 ml of water. Pour this acid solution into a 250-ml beaker and add 25 ml of hot ammonium hydroxide (1:1) making sure that ammonium hydroxide is in excess. Filter while hot and wash several times with hot water.
>
> Sulfur in the filtrate is determined by the method used for sulfate sulfur.
>
> Dissolve the precipitate of ferric hydroxide off the filter with the least possible quantity of concentrated hydrochloric acid, added drop by drop, and wash with small amounts of water. Heat the acid solution contained in a 250-ml beaker almost to boiling and add stannous chloride (10 grams of stannous chloride dissolved in 20 ml of hot concentrated hydrochloric acid and diluted to 200 ml with water) drop by drop from a burette until the solution is colorless, adding 3 or 4 drops in excess. Cool the solution rapidly and

> transfer it to a 600-ml beaker containing 250 ml of cold water. Add 10 ml of a saturated solution of mercuric chloride, stir the solution thoroughly, then add 20 ml of titrating solution (144 grams of manganeous sulfate, 1,040 ml of water, 280 ml of sulfuric acid, 1.84 specific gravity, and 280 ml of phosphoric acid, 1.71 specific gravity) and stir until well mixed. Titrate at once with 0.02 N potassium permanganate until the faintest pink color lasts for 10 seconds. The number of milliliters of 0.02 N potassium permanganate used, multiplied by 0.0558, gives the percentage of pyritic iron in the coal. Comparison is made with the gravimetric determination of pyritic sulfur, and if the calculated percentage is lower than that obtained directly, the calculated value is considered to be the correct one."

The organic sulfur is determined by subtracting the sum of the sulfate sulfur and pyritic sulfur from the total sulfur as determined in accordance with ASTM Method D 3177--"Test for Total Sulfur in the Analysis Sample of Coal and Coke."

14.3 WASHABILITY DATA

As discussed in Chapter 11, the determination of the preparation methods and the equipment needed to clean a specific coal is determined by washability studies. The washability study is an analysis or evaluation of the physical properties of coal which determine its amenability to improvements in quality by cleaning. The studies include stage crushing to release trapped impurities and specific gravity fractionation to show the quality and quantity of the cleaned product. The washability studies are made by testing the coal samples at preselected, carefully controlled specific gravities (float and sink analysis). Detailed chemical analyses of the various specific gravity fractions of the coal are used to compile the washability data, e.g.:

proximate analysis, ultimate analysis, calorific value, coal ash composition (see Chapter 11).

Typical washability data is shown in the following series of figures beginning with Table 14-2 General Washability data for the Upper Kittanning coal bed. Cumulative yield, ash, pyritic sulfur and total sulfur contents are displayed, showing theoretical yields and product quantities at various specific gravities when samples of coal were crushed to 1½ inch, 3/8 inch and 14 mesh top sizes. The interpolated sulfur and yield data shown in the figure were obtained as part of a computer program used by the U. S. Bureau of Mines which provided theoretical data that show at a glance the specific gravity of separation, the yield, the ash and the pyritic sulfur content to be expected at any desired total sulfur level.

Much more detailed washability data is available. For example, Table 14-3 represents a screen analysis of the Upper Kittanning Coal Bed showing the percent of total weight, ash content, pyritic sulfur and total sulfur by individual size fractions within each of two top size categories as direct percentages and as cumulative percentages. This information provides the data base needed to analyze the impact of the size fractions on the preparation plant.

Table 14-4 shows the general physical and chemical properties of the Upper Kittanning Coal Bed. Tables 14-5 and 14-6 show the detailed washability analysis of the same bed indicating the effects of stage crushing on the liberation of pyritic sulfur.

The U. S. Bureau of Mines Report of Investigations RI 8118 entitled Sulfur Reduction Potential of Coals of the United States, by J. A. Cavallano, M. T. Johnston and

Table 14-2
Typical Washability Data Plus Interpolated Values Provided by U. S. Bureau of Mines

STATE	PA. (BITUMINOUS)								COALBED UPPER KITTANNING			
COUNTY	CAMBRIA											
TOP SIZE	1-1/2 INCHES				3/8 INCH				14 MESH			
	CUMULATIVE WASHABILITY DATA, PERCENT											
PRODUCT	YIELD	ASH	PYRITIC SULFUR	TOTAL SULFUR	YIELD	ASH	PYRITIC SULFUR	TOTAL SULFUR	YIELD	ASH	PYRITIC SULFUR	TOTAL SULFUR
FLOAT-1.30	8.2	1.7	.04	.63	15.4	1.7	.04	.61	11.0	1.7	.03	.49
FLOAT-1.40	70.9	5.6	.30	.80	73.9	5.0	.17	.65	71.3	4.2	.13	.55
FLOAT-1.60	88.4	7.8	.77	1.32	86.7	6.8	.35	.83	88.0	6.1	.21	.70
TOTAL	100.0	11.6	2.16	2.70	100.0	12.0	2.28	2.80	100.0	11.5	2.22	2.74
	INTERPOLATED SULFUR DATA											
TOTAL SULFUR	S.G. OF SEP.	YIELD	ASH	PYRITIC SULFUR	S.G. OF SEP.	YIELD	ASH	PYRITIC SULFUR	S.G. OF SEP.	YIELD	ASH	PYRITIC SULFUR
.50									1.32	23.2	2.2	.05
1.00	1.50	77.6	6.4	.54								
1.50												
2.00												
2.50												
	INTERPOLATED YIELD DATA											
YIELD	S.G. OF SEP.	ASH	PYRITIC SULFUR	TOTAL SULFUR	S.G. OF SEP.	ASH	PYRITIC SULFUR	TOTAL SULFUR	S.G. OF SEP.	ASH	PYRITIC SULFUR	TOTAL SULFUR
50.0	1.37	3.6	.21	.74	1.36	2.7	.12	.63	1.36	2.5	.06	.53
60.0	1.38	4.5	.09	.77	1.38	3.5	.14	.64	1.38	3.2	.09	.54
70.0	1.40	5.5	.28	.78	1.39	4.5	.13	.65	1.40	4.1	.12	.54
80.0	1.49	6.7	.52	1.04	1.49	5.8	.25	.73	1.49	5.1	.17	.62
90.0												

SOURCE: RI 7633, "Sulfur Reduction Potential of the Coals of the United States," U. S. Bureau of Mines, 1972, by A. W. Deurbrouck.

Table 14-3

Screen Analyses of Upper Kittanning-Bed Coal

	Direct Percent				Cumulative Percent			
Size analysis	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
1-1/2 Inches Top Size:								
Minus 1-1/2-plus 1-inch	6.1	63.8	2.12	2.20	6.1	63.8	2.12	2.20
Minus 1-plus 3/4-inch	4.8	44.0	2.13	2.42	10.9	55.0	2.12	2.29
Minus 3/4-plus 1/2-inch	10.0	32.8	2.16	2.56	20.9	44.4	2.14	2.42
Minus 1/2-plus 3/8-inch	6.3	27.9	2.20	2.72	27.2	40.5	2.15	2.49
Minus 3/8-plus 1/4-inch	10.4	24.4	2.34	2.78	37.6	36.1	2.70	2.57
Minus 1/4-inch-plus 28-mesh	44.9	16.1	1.67	2.20	82.5	25.2	1.91	2.36
Minus 28-plus 48-mesh	5.9	13.4	1.32	1.88	88.4	24.4	1.87	2.33
Minus 48-plus 100-mesh	4.4	14.2	1.40	2.10	92.8	23.9	1.85	2.32
Minus 100-plus 200-mesh	3.1	15.0	1.78	2.47	95.9	23.6	1.84	2.33
Minus 200-mesh	4.1	17.1	1.38	2.10	100.0	23.2	1.83	2.32
3/8 Inch Top Size:								
Minus 3/8-plus 1/4-inch	17.1	38.2	2.44	2.73	17.1	38.2	2.44	2.73
Minus 1/4-inch plus 28-mesh	64.4	20.0	1.63	2.13	81.5	23.8	1.79	2.25
Minus 28-plus 48 mesh	6.8	15.2	1.42	1.94	88.3	23.1	1.77	2.23
Minus 48-plus 100 mesh	4.7	16.0	1.76	2.35	93.0	22.7	1.77	2.23
Minus 100-plus 200 mesh	3.4	16.6	2.22	2.74	96.4	22.5	1.78	2.25
Minus 200-mesh	3.6	19.0	2.03	2.47	100.0	22.4	1.79	2.26

Table 14-4

Chemical and Physical Properties
of Upper Kittanning-Bed Coal*

Analyses	Raw Coal
Chemical analysis, percent:	
Proximate:	
Volatile matter	15.9
Fixed carbon	60.6
Ash	23.5
Total	100.0
Pyritic sulfur	1.77
Total sulfur	2.3
Physical analysis:	
Hardgrove grindability index	91
Free swelling index	8.5
British Thermal Units	11710
Fusibility of Ash $^{\circ}$F:	
Initial deformation temperature	2480
Softening temperature	2570
Fluid temperature	2680

*Moisture-free basis.

Table 14-5

Detailed Washability Analyses of Upper Kittanning-Bed Coal
Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (1-1/2 inches top size)

	Direct Percent				Cumulative Percent			
Product	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
1-1/2 by 3/8	35.9				35.9			
Float - 1.30	4.1	3.6	.09	.72	4.1	3.6	.09	.72
1.35	28.9	6.5	.35	.89	33.0	6.1	.32	.86
1.40	12.5	11.9	1.09	1.49	45.5	7.9	.53	1.03
1.45	7.6	16.7	1.71	2.17	53.1	9.0	.70	1.20
1.50	4.4	20.9	2.31	2.84	57.5	9.9	.82	1.32
1.60	4.7	27.0	3.61	3.84	62.2	11.2	1.03	1.51
1.70	1.8	34.4	3.27	3.79	64.0	11.8	1.10	1.58
1.80	1.0	42.7	4.43	4.77	65.0	12.3	1.15	1.62
1.90	0.8	46.7	6.24	6.41	65.8	12.7	1.21	1.68
2.00	0.5	51.0	7.14	7.94	66.3	13.0	1.25	1.73
2.20	2.5	67.0	3.17	3.49	68.8	15.0	1.32	1.79
2.40	6.0	74.8	2.11	2.82	74.8	19.7	1.39	1.88
2.60	7.1	84.8	2.45	2.69	81.9	25.4	1.48	1.95
2.80	15.9	90.6	1.01	1.05	97.8	36.0	1.40	1.80
3.30	1.0	63.9	25.32	25.81	98.8	36.3	1.64	2.04
Sink - 3.30	1.2	62.8	32.50	32.86	100.0	36.7	2.02	2.41

Table 14-5 (continued)

Detailed Washability Analyses of Upper Kittanning-Bed Coal
Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (1-1/2-inches top size)

	Direct Percent				Cumulative Percent			
Product	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
28 by 100	15.7				100.0			
Float - 1.30	42.44	1.9	.07	.62	42.4	1.9	.07	.62
1.35	26.30	5.2	.13	.68	68.7	3.2	.09	.64
1.40	9.31	9.5	.28	.85	78.1	3.9	.12	.67
1.45	4.22	13.8	.47	1.02	82.3	4.4	.13	.69
1.50	2.23	17.9	.76	1.31	84.5	4.8	.15	.70
1.60	2.17	23.6	1.26	1.77	86.7	5.3	.18	.73
1.70	1.07	30.3	2.38	2.84	87.7	5.6	.20	.75
1.80	.40	40.1	4.08	4.54	88.1	5.7	.22	.77
1.90	.34	45.0	5.02	5.37	88.5	5.9	.24	.79
2.00	.32	52.0	5.91	6.19	88.8	6.0	.26	.81
2.20	.57	61.3	5.83	6.12	89.4	6.4	.30	.84
2.40	.90	69.0	4.11	4.17	90.3	7.0	.33	.88
2.60	.91	77.3	3.80	3.82	91.2	7.7	.37	.91
2.80	6.18	88.0	1.32	1.33	97.4	12.8	.43	.93
3.30	.80	65.8	24.68	25.43	98.2	13.2	.63	1.13
Sink - 3.30	1.84	64.8	38.24	40.30	100.0	14.2	1.32	1.85

Table 14-5 (continued)

Detailed Washability Analyses of Upper Kittanning-Bed Coal
Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (1-1/2-inches top size)

	Direct Percent				Cumulative Percent			
Product	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
3/8 by 28	48.4				84.3			
Float - 1.30	36.2	3.3	.08	164	36.2	3.3	.08	.64
1.35	29.5	7.0	.23	.77	65.7	4.9	.14	.69
1.40	7.5	11.8	.60	1.13	73.2	5.6	.19	.74
1.45	4.0	16.8	1.11	1.59	77.2	6.2	.24	.78
1.50	2.1	20.9	1.54	2.27	79.3	6.6	.27	.82
1.60	3.0	27.2	3.42	3.90	82.3	7.3	.39	.93
1.70	1.1	33.0	4.09	4.57	83.4	7.7	.43	.98
1.80	0.7	38.9	5.84	6.68	84.1	7.9	.48	1.03
1.90	0.6	44.3	7.90	8.44	84.7	8.2	.53	1.08
2.00	0.5	48.2	11.42	11.92	85.2	8.4	.60	1.14
2.20	1.2	63.2	6.16	6.51	86.4	9.2	.67	1.22
2.40	1.7	72.6	4.19	4.46	88.1	10.4	.74	1.28
2.60	2.0	79.9	5.17	5.33	90.1	11.9	.84	1.37
2.80	7.4	89.8	1.69	1.88	97.5	17.8	.90	1.41
3.30	1.0	60.0	32.70	33.37	98.5	18.3	1.23	1.73
Sink - 3.30	1.5	63.7	37.72	39.58	100.0	19.0	1.77	2.30

Table 14-5 (continued)

Detailed Washability Analyses of Upper Kittanning-Bed Coal
Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (1-1/2-inches top size)

	Direct Percent				Cumulative Percent			
Product	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
1-1/2 by 0	100.0				100.0			
Float - 1.30	25.7	3.0	.08	.63	25.7	3.0	.08	.63
1.35	28.8	6.6	.26	.80	54.5	4.9	.18	.72
1.40	9.6	11.5	.78	1.25	64.1	5.9	.27	.80
1.45	5.3	16.4	1.34	1.81	69.4	6.7	.35	.88
1.50	2.9	20.5	1.86	2.46	72.3	7.3	.41	.94
1.60	3.5	26.8	3.30	3.66	75.8	8.2	.54	1.07
1.70	1.3	33.3	3.48	3.97	77.1	8.6	.59	1.12
1.80	.8	40.7	5.04	5.61	77.9	8.9	.64	1.16
1.90	.6	45.4	6.92	7.27	78.5	9.2	.69	1.21
2.00	.5	49.6	9.24	9.82	79.0	9.4	.74	1.26
2.20	1.6	65.3	4.43	4.76	80.6	10.5	.81	1.33
2.40	3.1	74.0	2.74	3.31	83.7	12.9	.88	1.40
2.60	3.6	83.2	3.22	3.43	87.3	15.8	.98	1.48
2.80	10.3	90.1	1.27	1.36	97.6	23.6	1.01	1.47
3.30	.9	62.2	28.92	29.53	98.5	24.0	1.28	1.74
Sink - 3.30	1.5	63.7	36.27	37.73	100.0	24.6	1.79	2.27
Minus - 100	3.3	16.0	1.74	2.18	[1] 100.0	[1] 24.3	[1] 1.79	[1] 2.27

[1] These are cumulative values for the float-and-sink plus the minus 100 mesh material.

Table 14-6

Detailed Washability Analyses of Upper Kittanning-Bed Coal
Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (3/8 inch top size)

	Direct Percent				Cumulative Percent			
Product	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
3/8 by 28	84.5				84.5			
Float - 1.30	22.4	2.7	.06	.58	22.4	2.7	.06	.58
1.35	33.2	6.4	.19	.68	55.6	4.9	.13	.63
1.40	9.4	11.8	.57	1.03	65.0	5.9	.20	.69
1.45	5.1	17.0	.96	1.55	70.1	6.7	.25	.75
1.50	2.5	21.0	1.48	1.91	72.6	7.2	.29	.79
1.60	3.6	27.7	2.70	3.19	76.2	8.1	.41	.91
1.70	1.1	33.8	3.62	4.08	77.3	8.5	.45	.95
1.80	0.8	41.4	4.62	4.80	78.1	8.8	.49	.99
1.90	0.6	47.5	6.13	6.13	78.7	9.1	.54	1.03
2.00	0.4	50.6	8.78	9.10	79.1	9.3	.58	1.07
2.20	1.8	67.2	3.89	4.11	80.9	10.6	.65	1.14
2.40	2.7	74.8	2.61	3.09	83.6	12.7	.72	1.20
2.60	2.8	81.0	3.33	3.96	86.4	14.9	.80	1.29
2.80	11.1	90.4	1.11	1.33	97.5	23.5	.83	1.29
3.30	1.0	62.3	26.47	28.15	98.5	23.9	1.10	1.57
Sink - 3.30	1.5	63.2	37.52	38.97	100.0	24.5	1.70	2.13

Table 14-6 (continued)

Detailed Washability Analyses of Upper Kittanning-Bed Coal
Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (3/8 inch top size)

	Direct Percent				Cumulative Percent			
Product	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
28 by 100	15.5				100.0			
Float - 1.30	42.2	2.0	.05	.61	42.2	2.0	.05	.61
1.35	25.8	5.3	.14	.73	68.0	3.2	.08	.65
1.40	8.7	9.8	.29	.91	76.7	3.9	.10	.68
1.45	4.3	14.5	.53	1.02	81.0	4.5	.12	.70
1.50	2.0	19.6	1.36	1.88	83.0	4.9	.15	.73
1.60	2.3	24.1	1.34	1.77	85.3	5.4	.19	.75
1.70	1.0	31.4	2.46	2.78	86.3	5.7	.21	.78
1.80	0.5	39.3	3.73	4.11	86.8	5.9	.23	.80
1.90	0.4	46.0	4.91	5.02	87.2	6.1	.25	.82
2.00	0.3	52.2	5.45	5.91	87.5	6.2	.27	.83
2.20	0.5	60.9	5.42	5.64	88.0	6.5	.30	.86
2.40	1.6	72.4	2.85	2.98	89.6	7.7	.35	.90
2.60	1.1	82.0	2.69	2.72	90.7	8.6	.38	.92
2.80	6.4	88.6	1.15	1.15	97.1	13.9	.43	.93
3.30	1.0	67.0	22.06	22.13	98.1	14.4	.65	1.16
Sink - 3.30	1.9	64.8	38.87	40.73	100.0	15.4	1.38	1.91

Table 14-6 (continued)

Detailed Washability Analyses of Upper Kittanning-Bed Coal
Showing the Effect of Crushing on the Liberation of Pyritic Sulfur (3/8 inch top size)

	Direct Percent				Cumulative Percent			
Product	Weight	Ash	Pyritic Sulfur	Total Sulfur	Weight	Ash	Pyritic Sulfur	Total Sulfur
3/8 by 0	100.0				100.0			
Float - 1.30	25.4	2.5	.06	.58	25.4	2.5	.06	.58
1.35	32.0	6.3	.18	.68	57.4	4.6	.13	.64
1.40	9.3	11.5	.53	1.01	66.7	5.6	.18	.69
1.45	5.0	16.6	.90	1.47	71.7	6.3	.23	.74
1.50	2.4	20.8	1.46	1.90	74.1	6.8	.27	.78
1.60	3.4	27.3	2.56	3.03	77.5	7.7	.37	.88
1.70	1.1	33.4	3.44	3.88	78.6	8.1	.42	.92
1.80	.8	41.1	4.52	4.72	79.4	8.4	.45	.96
1.90	.6	47.3	6.00	6.01	80.0	8.6	.49	.99
2.00	.4	50.8	8.35	8.69	80.4	8.9	.53	1.03
2.20	1.6	66.8	3.96	4.18	82.0	10.0	.60	1.09
2.40	2.5	74.5	2.63	3.07	84.5	11.9	.66	1.15
2.60	2.5	81.0	3.28	3.87	87.0	13.9	.74	1.23
2.80	10.4	90.2	1.11	1.31	97.4	22.0	.78	1.24
3.30	1.0	63.0	25.77	27.29	98.4	22.5	1.03	1.51
Sink - 3.30	1.6	63.4	37.77	39.29	100.0	23.1	1.61	2.10
Minus 100	7.8	18.2	2.11	2.60	[1] 100.0	[1] 22.8	[1] 1.66	[1] 2.14

[1] These are cumulative values for the float-and-sink plus the minus 100 mesh material.

A. W. Deurbrouck, published in 1976 represents the results of washability studies of 455 raw coal channel samples with special emphasis on sulfur reduction. The 455 samples represent 70% of the total annual utility coal production sources for the United States.

The analysis of these samples reported on by the U. S. Bureau of Mines have been compiled specifically to show what effect size reduction and specific gravity fractionation have on the liberation and subsequent removal of pyritic sulfur and other impurities. According to the U. S. Bureau of Mines, the "cumulative weight and Btu recovery, Btu per pound, ash, pyritic sulfur, total sulfur and pounds SO_2 emission per million Btu levels are given showing gravities when the coal samples were crushed to 1½ inch, 3/8 inch and 14 mesh top sizes. The Btu per pound values for the float 1.60 specific gravity products and the total or raw coal products were obtained by actual analysis; those of the float 1.30, 1.40 and 1.90 specific gravity products were obtained by interpolation from a plot of cumulative ash versus cumulative Btu per pound. The pounds SO_2 emission per million Btu were calculated using the corresponding Btu per pound (moisture-free basis) and total sulfur content (moisture-free basis) and assumes that all of the sulfur in the coal goes out of the stack as SO_2. Actual emissions may vary because as-fired coals will contain some moisture and all of the sulfur may not go out the stack as SO_s." All chemical analyses are reported on a moisture-free basis. Raw coal moisture is the moisture contained in the sample after being air dried at the coal preparation laboratory based on the assumption that the moisture content thus arrived at and reported would closely simulate the moisture content of the coal burned at the selected power plants.

In addition, the samples collected and analyzed by the U. S. Bureau of Mines are broken down into six regions (Northern Appalachian, Southern Appalachian, Alabama Region, Eastern Midwest Region, Western Midwest Region and Western Region) refined and shown in Chapter 20. A sample of the data display is shown in Table 14-7.

Tables 14-8, 9, 10 and 11 are statistical evaluations of the composited washability data as displayed in Table 14-7. The data for each sample and a composite of all the samples collected for each individual coalbed, or a composite of all the samples collected for all the coalbeds of a region, showing the effect on ash, pyritic sulfur and total sulfur contents when crushing the coal to three top sizes, 1½ inches, 3/8 inch and 14 mesh are included. Average values are given plus standard deviation (sigma) values. Average values are the arithmetic means of the data involved in computing any given average. Because the number of pieces of data involved in the computation of an average gives one measure of credence of the average, this number is shown in all output. Sigma values are given to show the spread of the data about the average. This sigma is the standard deviation. For a normal distribution, 68 percent of the cases should fall between the "average" ($\overline{X}$), ±s; 95 percent of the cases between the "average" $\overline{X} \pm 2s$, and 99.7 percent of the cases between the "average" $\overline{X} \pm 3s$. Thus, it is desirable to have "N," the number of samples, large and s, "sigma," as small as possible.

Specifically Table 14-8 is a sample projected by percent weight recovery of a coal sample of a particular coal bed showing the effects of stage crushing and gravimetric separation on the specific coal. Individual values are presented for samples crushed to 1½ inch top size, 3/8 inch top size and 14 mesh top size for each of the six

Table 14-7

Sample Washability Data from
U. S. Bureau of Mines RI-8118

STATE:	Pennsylvania (Bituminous)	COALBED:	Lower Kittanning
COUNTY:	Cambria	RAW COAL MOISTURE:	.8%

CUMULATIVE WASHABILITY DATA

Product	Recovery,%		BTU/LB	Ash,%	Sulfur,%		LB SO_2/M BTU
	Weight	BTU			Pyritic	Total	
SAMPLE CRUSHED TO PASS 1-1/2 INCHES							
Float - 1.30	61.0	64.4	15073	3.3	.15	.90	1.2
Float - 1.40	85.6	89.0	14858	4.7	.32	1.05	1.4
Float - 1.60	94.1	96.2	14611	6.3	.49	1.18	1.6
Total	100.0	100.0	14288	8.4	1.31	2.01	2.8
EPA Standard	61.9	65.2	15068	3.3	.15	.90	1.20
SAMPLE CRUSHED TO PASS 3/8 INCH							
Float - 1.30	65.3	69.1	15227	2.3	.20	.81	1.1
Float - 1.40	87.1	90.7	14996	3.8	.29	.88	1.2
Float - 1.60	93.3	96.0	14811	5.0	.39	.97	1.3
Total	100.0	100.0	14396	7.7	1.19	1.81	2.5
EPA Standard	90.1	93.6	14960	4.1	.31	.90	1.20

Table 14-7 (continued)

Sample Washability Data from
U. S. Bureau of Mines RI-8118

SAMPLE CRUSHED TO PASS 14 MESH							
Product	Recovery,%		BTU/LB	Ash,%	Sulfur,%		LB SO_2/M BTU
	Weight	BTU			Pyritic	Total	
Float - 1.30	59.2	63.4	15274	2.0	.09	.83	1.1
Float - 1.40	85.3	89.7	15012	3.7	.24	.85	1.1
Float - 1.60	92.6	96.1	14811	5.0	.35	.94	1.3
Total	100.0	100.0	14272	8.5	1.29	1.90	2.7
EPA Standard	88.9	92.9	14913	4.3	.36	.89	1.20

Table 14-8

COALBED: LOWER KITTANNING
STATE: PA
RAW COAL MOISTURE, PERCENT: .7

WEIGHT RECOVERY	NO OF SAMPLES	ASH, PERCENT RAW: 21.3 SIGMA: 0.0				PYRITIC SULFUR, PERCENT RAW: 3.93 SIGMA: 0.0				TOTAL SULFUR, PERCENT RAW: 4.63 SIGMA: 0.0			
		AVERAGE	SIGMA	REDUCTION	SIGMA	AVERAGE	SIGMA	REDUCTION	SIGMA	AVERAGE	SIGMA	REDUCTION	SIGMA
SAMPLE CRUSHED TO PASS 1-1/2 INCH													
50.0	1	4.1	0.0	81.2	0.0	.16	0.0	95.9	0.0	1.17	0.0	74.5	0.0
60.0	1	5.2	0.0	76.0	0.0	.37	0.0	90.4	0.0	1.20	0.0	73.9	0.0
70.0	1	7.0	0.0	67.8	0.0	.76	0.0	80.5	0.0	1.58	0.0	65.6	0.0
80.0	1	10.1	0.0	53.3	0.0	1.44	0.0	63.1	0.0	2.24	0.0	51.2	0.0
90.0	1	15.1	0.0	30.6	0.0	2.48	0.0	36.2	0.0	3.25	0.0	29.3	0.0
100.0	1	21.7	0.0	0.0	0.0	3.89	0.0	0.0	0.0	4.59	0.0	0.0	0.0
SAMPLE CRUSHED TO PASS 3/8 INCH													
50.0	1	3.6	0.0	82.7	0.0	.29	0.0	92.5	0.0	1.13	0.0	75.4	0.0
60.0	1	4.5	0.0	78.3	0.0	.31	0.0	91.9	0.0	1.15	0.0	74.9	0.0
70.0	1	6.2	0.0	70.7	0.0	.55	0.0	85.8	0.0	1.37	0.0	70.0	0.0
80.0	1	9.1	0.0	56.7	0.0	1.12	0.0	71.1	0.0	1.92	0.0	58.1	0.0
90.0	1	14.1	0.0	33.0	0.0	2.23	0.0	42.3	0.0	3.00	0.0	34.5	0.0
100.0	1	21.0	0.0	0.0	0.0	3.87	0.0	0.0	0.0	4.58	0.0	0.0	0.0
SAMPLE CRUSHED TO PASS 14 MESH													
50.0	1	3.2	0.0	84.8	0.0	.26	0.0	93.5	0.0	1.10	0.0	76.7	0.0
60.0	1	4.5	0.0	78.9	0.0	.28	0.0	93.0	0.0	1.10	0.0	76.7	0.0
70.0	1	6.6	0.0	68.9	0.0	.53	0.0	86.9	0.0	1.36	0.0	71.3	0.0
80.0	1	10.0	0.0	53.0	0.0	1.16	0.0	71.3	0.0	1.97	0.0	58.2	0.0
90.0	1	14.9	0.0	30.0	0.0	2.34	0.0	42.1	0.0	3.10	0.0	34.2	0.0
100.0	1	21.3	0.0	0.0	0.0	4.04	0.0	0.0	0.0	4.72	0.0	0.0	0.0

WEIGHT RECOVERY	NO OF SAMPLES	BTU RECOVERY, PERCENT RAW: 100.0 SIGMA: 0.0				BTU PER POUND RAW: 11956 SIGMA: 0				POUNDS OF SO2/M BTU RAW: 7.7 SIGMA: 0.0			
		AVERAGE	SIGMA	REDUCTION	SIGMA	AVERAGE	SIGMA	%INCREASE	SIGMA	AVERAGE	SIGMA	%REDUCTION	SIGMA
SAMPLE CRUSHED TO PASS 1-1/2 INCH													
50.0	1	61.7	0.0	38.3	0.0	14563	0	22	0	1.6	0.0	79.3	0.0
60.0	1	73.0	0.0	27.0	0.0	14435	0	21	0	1.6	0.0	79.3	0.0
70.0	1	83.5	0.0	16.5	0.0	14196	0	19	0	2.2	0.0	70.9	0.0
80.0	1	91.9	0.0	8.1	0.0	13492	0	13	0	3.4	0.0	55.6	0.0
90.0	1	97.3	0.0	2.7	0.0	12695	0	6	0	5.2	0.0	31.9	0.0
100.0	1	100.0	0.0	0.0	0.0	11899	0	0	0	7.7	0.0	0.0	0.0
SAMPLE CRUSHED TO PASS 3/8 INCH													
50.0	1	61.4	0.0	38.6	0.0	14656	0	22	0	1.5	0.0	80.2	0.0
60.0	1	72.9	0.0	27.1	0.0	14531	0	21	0	1.5	0.0	80.0	0.0
70.0	1	83.5	0.0	16.5	0.0	14323	0	19	0	1.9	0.0	74.7	0.0
80.0	1	92.1	0.0	7.9	0.0	13661	0	13	0	2.9	0.0	61.8	0.0
90.0	1	97.6	0.0	2.4	0.0	12835	0	6	0	4.8	0.0	36.7	0.0
100.0	1	100.0	0.0	0.0	0.0	12009	0	0	0	7.6	0.0	0.0	0.0
SAMPLE CRUSHED TO PASS 14 MESH													
50.0	1	62.0	0.0	38.0	0.0	14670	0	22	0	1.5	0.0	81.0	0.0
60.0	1	73.2	0.0	26.8	0.0	14540	0	21	0	1.5	0.0	81.1	0.0
70.0	1	83.4	0.0	16.6	0.0	14249	0	19	0	1.9	0.0	76.1	0.0
80.0	1	91.6	0.0	8.4	0.0	13549	0	13	0	2.9	0.0	62.7	0.0
90.0	1	97.1	0.0	2.9	0.0	12755	0	6	0	5.0	0.0	37.1	0.0
100.0	1	100.0	0.0	0.0	0.0	11962	0	0	0	7.9	0.0	0.0	0.0

criteria: percent of ash, percent of pyritic sulfur, percent total sulfur, percent Btu recovery, Btu per pound and pounds of SO_2 per million Btu. For example, reviewing Table 14-8, if the particular coal shown is cleaned by physical methods with a yield of 50% by weight at a top size of 1½ inch, then:

- The ash content is reduced from 21.7% to 4.1 (a reduction of 81.2%),
- The pyritic sulfur content is reduced from 3.89% to 0.16% (a reduction of 95.9%),
- The total sulfur content is reduced from 4.59% to 1.17% (a reduction of 74.5%),
- The Btu recovery is reduced from 100% to 61.7% (a reduction of 38.3%),
- However, the Btu per pound increases from 11899, to 14563 (an increase of 22%) and
- The pounds of SO_2 per million Btu are reduced from 7.7 to 1.6 (a reduction of 79.3%).

For this particular coal, following the table through to final crushing to pass 14 mesh yields little further significant reduction in total sulfur and only a 0.1% reduction in pounds SO_2 per million Btu.

Table 14-9 shows the effects of crushing on liberation of impurities by displaying the quality of theoretical products obtained from cumulative interpolated washability data at 50-, 60-, 70-, 80-, 90- and 100-percent Btu recovery levels. The data are arranged and read the same as for Table 14-8.

Table 14-10 shows the effects of crushing on liberation of impurities by displaying the quality of theoretical products obtained from cumulative interpolated washability data at specific total sulfur levels beginning at 2.2 and dropping down to 1.2 percent.

Table 14-9

```
COALBED:  LOWER KITTANNING
STATE:    PA
RAW COAL MOISTURE,PERCENT:    .7

                              WEIGHT,PERCENT                        ASH,PERCENT                       PYRITIC SULFUR,PERCENT
                           RAW:100.0   SIGMA: 0.0              RAW: 21.3   SIGMA: 0.0                RAW: 3.93   SIGMA: 0.0

 BTU        NO OF       AVERAGE SIGMA  REDUCTION SIGMA      AVERAGE SIGMA  REDUCTION SIGMA      AVERAGE SIGMA  REDUCTION SIGMA
RECOVERY    SAMPLES
.......................................................SAMPLE CRUSHED TO PASS 1-1/2 INCH.........................................
 50.0         1            40.3    0.0     59.7    0.0          3.9    0.0     81.9    0.0           .19    0.0     95.1    0.0
 60.0         1            48.4    0.0     51.6    0.0          3.8    0.0     82.3    0.0           .31    0.0     92.1    0.0
 70.0         1            57.2    0.0     42.8    0.0          4.8    0.0     78.0    0.0           .28    0.0     92.7    0.0
 80.0         1            66.6    0.0     33.4    0.0          6.3    0.0     70.9    0.0           .61    0.0     84.3    0.0
 90.0         1            78.8    0.0     21.2    0.0         10.3    0.0     52.4    0.0          1.47    0.0     62.1    0.0
100.0         1           100.0    0.0      0.0    0.0         21.7    0.0      0.0    0.0          3.89    0.0      0.0    0.0
.......................................................SAMPLE CRUSHED TO PASS 3/8 INCH...........................................
 50.0         1            40.6    0.0     59.4    0.0          3.3    0.0     84.1    0.0           .21    0.0     94.5    0.0
 60.0         1            48.7    0.0     51.3    0.0          3.5    0.0     83.4    0.0           .29    0.0     92.6    0.0
 70.0         1            57.4    0.0     42.6    0.0          4.2    0.0     80.1    0.0           .26    0.0     93.2    0.0
 80.0         1            66.6    0.0     33.4    0.0          5.5    0.0     73.6    0.0           .46    0.0     88.2    0.0
 90.0         1            78.3    0.0     21.7    0.0          9.0    0.0     57.0    0.0          1.13    0.0     70.8    0.0
100.0         1           100.0    0.0      0.0    0.0         21.0    0.0      0.0    0.0          3.87    0.0      0.0    0.0
.......................................................SAMPLE CRUSHED TO PASS 14 MESH.............................................
 50.0         1            40.0    0.0     60.0    0.0          3.2    0.0     85.0    0.0           .20    0.0     95.0    0.0
 60.0         1            48.1    0.0     51.9    0.0          3.9    0.0     81.6    0.0           .26    0.0     93.6    0.0
 70.0         1            56.9    0.0     43.1    0.0          3.9    0.0     81.5    0.0           .22    0.0     94.6    0.0
 80.0         1            66.6    0.0     33.4    0.0          5.8    0.0     72.7    0.0           .43    0.0     89.3    0.0
 90.0         1            79.1    0.0     20.9    0.0         10.2    0.0     52.3    0.0          1.26    0.0     68.7    0.0
100.0         1           100.0    0.0      0.0    0.0         21.3    0.0      0.0    0.0          4.04    0.0      0.0    0.0

                           TOTAL SULFUR, PERCENT                   BTU PER POUND                     POUNDS OF SO2/M BTU
                           RAW: 4.63   SIGMA: 0.0              RAW:   11956  SIGMA:    0              RAW:  7.7   SIGMA: 0.0

 BTU        NO OF       AVERAGE SIGMA  REDUCTION SIGMA      AVERAGE SIGMA  %INCREASE SIGMA      AVERAGE SIGMA  %REDUCTION SIGMA
RECOVERY    SAMPLES
.......................................................SAMPLE CRUSHED TO PASS 1-1/2 INCH.........................................
 50.0         1            1.07    0.0     76.6    0.0        14682      0       23      0           1.5    0.0     81.1    0.0
 60.0         1            1.16    0.0     74.7    0.0        14573      0       22      0           1.6    0.0     79.4    0.0
 70.0         1            1.11    0.0     75.8    0.0        14464      0       21      0           1.4    0.0     81.2    0.0
 80.0         1            1.43    0.0     68.9    0.0        14300      0       20      0           2.0    0.0     74.2    0.0
 90.0         1            2.27    0.0     50.5    0.0        13432      0       12      0           3.5    0.0     54.7    0.0
100.0         1            4.59    0.0      0.0    0.0        11899      0        0      0           7.7    0.0      0.0    0.0
.......................................................SAMPLE CRUSHED TO PASS 3/8 INCH...........................................
 50.0         1            1.05    0.0     77.0    0.0        14774      0       23      0           1.4    0.0     81.7    0.0
 60.0         1            1.12    0.0     75.5    0.0        14665      0       22      0           1.5    0.0     80.3    0.0
 70.0         1            1.10    0.0     76.0    0.0        14557      0       21      0           1.4    0.0     81.1    0.0
 80.0         1            1.29    0.0     71.9    0.0        14422      0       20      0           1.8    0.0     76.8    0.0
 90.0         1            1.94    0.0     57.8    0.0        13667      0       13      0           2.9    0.0     61.5    0.0
100.0         1            4.58    0.0      0.0    0.0        12009      0        0      0           7.6    0.0      0.0    0.0
.......................................................SAMPLE CRUSHED TO PASS 14 MESH.............................................
 50.0         1            1.05    0.0     77.8    0.0        14794      0       23      0           1.4    0.0     81.9    0.0
 60.0         1            1.09    0.0     76.8    0.0        14683      0       22      0           1.5    0.0     81.1    0.0
 70.0         1            1.14    0.0     75.9    0.0        14571      0       21      0           1.6    0.0     80.3    0.0
 80.0         1            1.26    0.0     73.4    0.0        14373      0       20      0           1.7    0.0     78.1    0.0
 90.0         1            2.07    0.0     56.1    0.0        13483      0       12      0           3.1    0.0     60.3    0.0
100.0         1            4.72    0.0      0.0    0.0        11962      0        0      0           7.9    0.0      0.0    0.0
```

Table 14-10

```
COALBED:  LOWER KITTANNING
STATE:    PA
RAW COAL MOISTURE,PERCENT:    .7

                              WEIGHT,PERCENT                          ASH,PERCENT                      PYRITIC SULFUR,PERCENT
                          RAW:100.0   SIGMA: 0.0                RAW: 21.3   SIGMA: 0.0                 RAW: 3.93   SIGMA: 0.0
TOTAL     NO OF      AVERAGE SIGMA  REDUCTION SIGMA       AVERAGE SIGMA  REDUCTION SIGMA       AVERAGE SIGMA  REDUCTION SIGMA
SULFUR    SAMPLES
..................................................SAMPLE CRUSHED TO PASS 1-1/2 INCH..............................................
  1.2        1           54.8    0.0     45.2    0.0            5.0    0.0     76.6    0.0           .36    0.0     90.9    0.0
  1.4        1           68.0    0.0     32.0    0.0            6.3    0.0     70.6    0.0           .59    0.0     85.0    0.0
  1.6        1           70.3    0.0     29.7    0.0            7.2    0.0     66.4    0.0           .79    0.0     80.0    0.0
  1.8        1           74.7    0.0     25.3    0.0            8.0    0.0     62.5    0.0           .98    0.0     75.1    0.0
  2.0        1           78.6    0.0     21.4    0.0            8.9    0.0     58.1    0.0          1.18    0.0     69.9    0.0
  2.2        1           82.2    0.0     17.8    0.0            9.9    0.0     53.7    0.0          1.39    0.0     64.8    0.0
..................................................SAMPLE CRUSHED TO PASS 3/8 INCH................................................
  1.2        1           60.5    0.0     39.5    0.0            4.9    0.0     77.2    0.0           .37    0.0     90.7    0.0
  1.4        1           70.6    0.0     29.4    0.0            6.4    0.0     70.0    0.0           .58    0.0     85.3    0.0
  1.6        1           77.4    0.0     22.6    0.0            7.7    0.0     64.1    0.0           .79    0.0     80.0    0.0
  1.8        1           83.5    0.0     16.5    0.0            8.9    0.0     58.2    0.0           .99    0.0     74.7    0.0
  2.0        1           88.9    0.0     11.1    0.0           10.1    0.0     52.4    0.0          1.20    0.0     69.4    0.0
  2.2        1           93.6    0.0      6.4    0.0           11.3    0.0     47.0    0.0          1.41    0.0     64.1    0.0
..................................................SAMPLE CRUSHED TO PASS 14 MESH.................................................
  1.2        1           67.0    0.0     33.0    0.0            5.5    0.0     74.3    0.0           .38    0.0     90.3    0.0
  1.4        1           71.2    0.0     28.8    0.0            7.1    0.0     66.8    0.0           .58    0.0     85.4    0.0
  1.6        1           77.5    0.0     22.5    0.0            8.5    0.0     60.2    0.0           .77    0.0     80.5    0.0
  1.8        1           83.2    0.0     16.8    0.0            9.9    0.0     53.4    0.0           .96    0.0     75.6    0.0
  2.0        1           88.3    0.0     11.7    0.0           11.3    0.0     47.0    0.0          1.16    0.0     70.5    0.0
  2.2        1           92.8    0.0      7.2    0.0           12.6    0.0     41.1    0.0          1.36    0.0     65.4    0.0

                           BTU RECOVERY, PERCENT                   BTU PER POUND                    POUNDS OF SO2/M BTU
                          RAW:100.0   SIGMA: 0.0              RAW:   11956  SIGMA:    0              RAW:  7.7   SIGMA: 0.0
TOTAL     NO OF      AVERAGE SIGMA  REDUCTION SIGMA       AVERAGE SIGMA  %INCREASE SIGMA       AVERAGE SIGMA  %REDUCTION SIGMA
SULFUR    SAMPLES
..................................................SAMPLE CRUSHED TO PASS 1-1/2 INCH..............................................
  1.2        1           66.7    0.0     33.3    0.0          14530    0       21      0             1.6    0.0     79.0    0.0
  1.4        1           81.9    0.0     18.1    0.0          14330    0       19      0             1.9    0.0     75.1    0.0
  1.6        1           83.7    0.0     16.3    0.0          14187    0       18      0             2.3    0.0     70.6    0.0
  1.8        1           88.1    0.0     11.9    0.0          14037    0       17      0             2.6    0.0     66.1    0.0
  2.0        1           91.9    0.0      8.1    0.0          13884    0       16      0             3.0    0.0     61.6    0.0
  2.2        1           95.3    0.0      4.7    0.0          13731    0       14      0             3.3    0.0     57.0    0.0
..................................................SAMPLE CRUSHED TO PASS 3/8 INCH................................................
  1.2        1           73.1    0.0     26.9    0.0          14544    0       21      0             1.6    0.0     79.1    0.0
  1.4        1           84.0    0.0     16.0    0.0          14305    0       19      0             2.0    0.0     74.6    0.0
  1.6        1           90.9    0.0      9.1    0.0          14138    0       18      0             2.3    0.0     69.8    0.0
  1.8        1           97.0    0.0      3.0    0.0          13995    0       17      0             2.7    0.0     65.1    0.0
  2.0        1           97.2    0.0      2.6    0.0          13852    0       15      0             3.1    0.0     60.5    0.0
  2.2        1           97.4    0.0      2.6    0.0          13709    0       14      0             3.4    0.0     55.8    0.0
..................................................SAMPLE CRUSHED TO PASS 14 MESH.................................................
  1.2        1           80.9    0.0     19.1    0.0          14459    0       20      0             1.6    0.0     78.7    0.0
  1.4        1           84.5    0.0     15.5    0.0          14206    0       18      0             2.0    0.0     74.8    0.0
  1.6        1           90.6    0.0      9.4    0.0          14056    0       17      0             2.3    0.0     70.7    0.0
  1.8        1           96.1    0.0      3.9    0.0          13920    0       16      0             2.6    0.0     66.6    0.0
  2.0        1           96.4    0.0      3.6    0.0          13786    0       15      0             2.9    0.0     62.4    0.0
  2.2        1           96.6    0.0      3.4    0.0          13651    0       14      0             3.2    0.0     58.1    0.0
```

Table 14-11 shows the effect of crushing on liberation of impurities by displaying the quality of theoretical products obtained from cumulative interpolated washability data on specific, theoretical pounds of SO_2 emissions per million Btu fired.

Generally, the data presented in RI 8118 show that as the recoveries increased, the ash, pyritic sulfur, total sulfur, weight, and pounds of SO_2 imission per million Btu also increased. However, the Btu per pound decreased since the ash content increased. As the sample was crushed, more impurities were released and readily separated. That is, the ash, pyritic sulfur, total sulfur, weight recovery and pounds of SO_2 emission per million Btu generally decreased while the Btu per pound increased when the sample was crushed to the finer top sizes and the higher specific gravity material was removed.

Figure 14-3 is a nomograph showing the SO_2 emissions which will result from burning coals of various sulfur and Btu contents. When using the nomograph or the formula shown therein, it is important to maintain consistency and to be sure that both the Btu per pound and sulfur values are on an as received, moisture-free or moisture-and-ash free basis. For example, a coal containing 0.8 percent sulfur and 13,100 Btu per pound could meet the EPA SO_2 emission standard; however, a coal of the same sulfur content but containing only 10,500 Btu per pound would produce 1.5 pounds of SO_2 per million Btu and would therefore be out of compliance.

The following summary based on all of the 455 samples is taken directly from RI 8118:

> "The 455 raw coal samples averaged 14.9 percent ash, 1.91 percent pyritic sulfur, 3.02 percent total sulfur and 12,574 Btu per pound, which

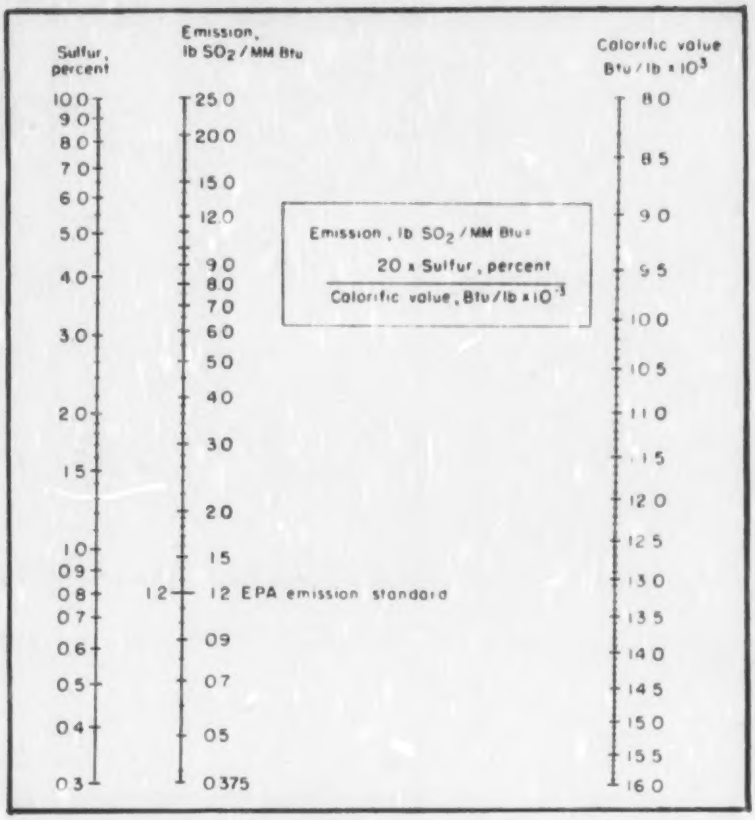


Figure 14-3

Nomograph Relating Sulfur Content and Calorific Value in Coals to Pounds of SO_2 Emission per Million Btu

would produce 4.9 pounds SO_2/MM Btu fired at the power plant. The raw coal sulfur contents averaged 63 percent pyritic sulfur and 37 percent organic sulfur.

The ash, pyritic sulfur, total sulfur and heating value contents varied considerably as would be expected when washability data of coals from various regions of the United States are evaluated. This is evidenced by the large sigma values for each of the parameters evaluated.

Figure 14-4 shows that significant reduction of impurities can be obtained, especially ash and

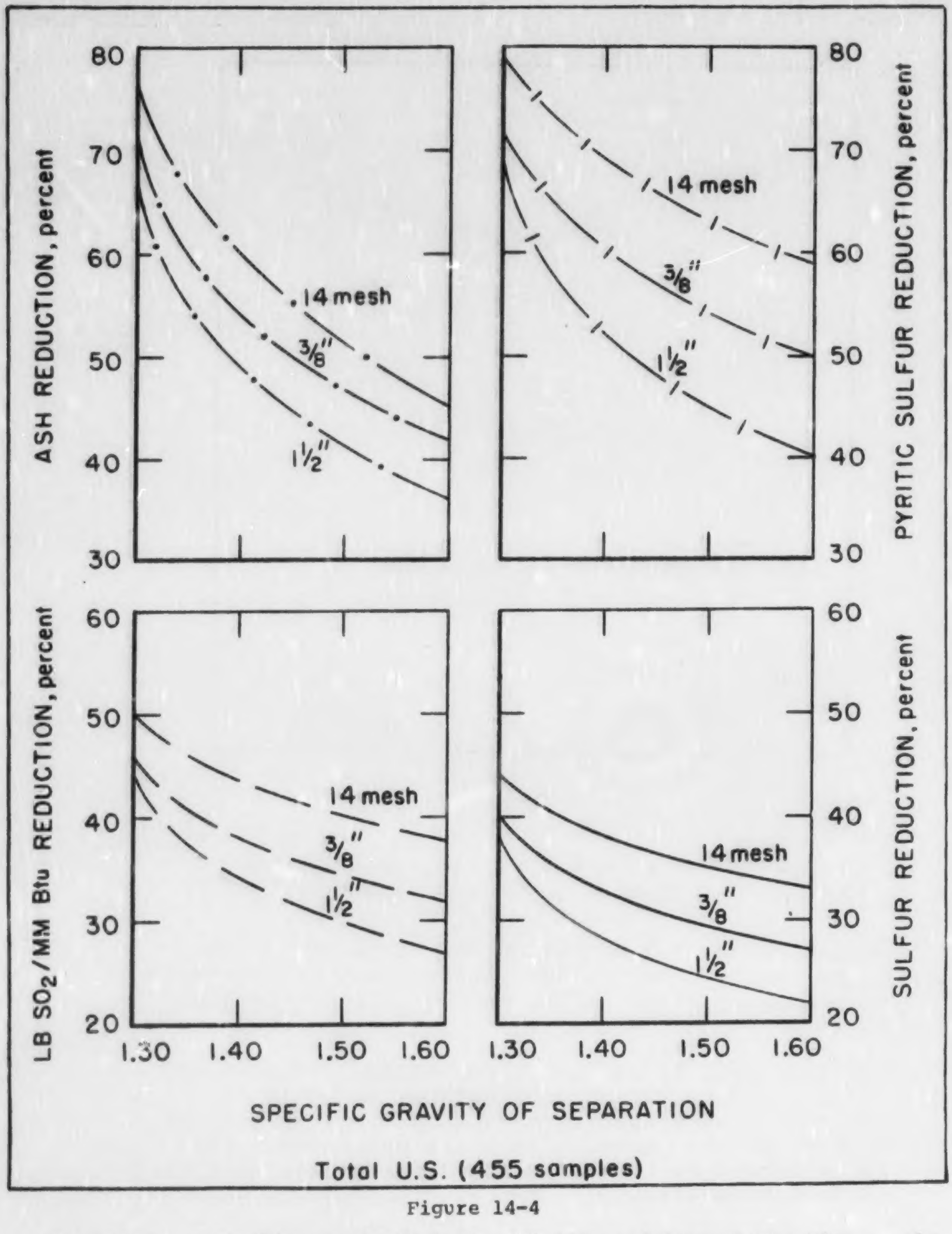


Figure 14-4

The Effect of Crushing to 1 1/2 inch, 3/8 inch and 14-mesh Top Size on the Reduction of Ash, Pyritic Sulfur, Total Sulfur and Pounds SO_2 Emission per Million Btu at Various Specific Gravities of Separation for All U.S. Coals pyritic sulfur contents, by crushing and gravimetric separation.

Figure 14-5 shows that only 14 percent of raw coal samples as mined could meet the current EPA SO_2 emission standard of 1.2 pounds SO_2/MM Btu.

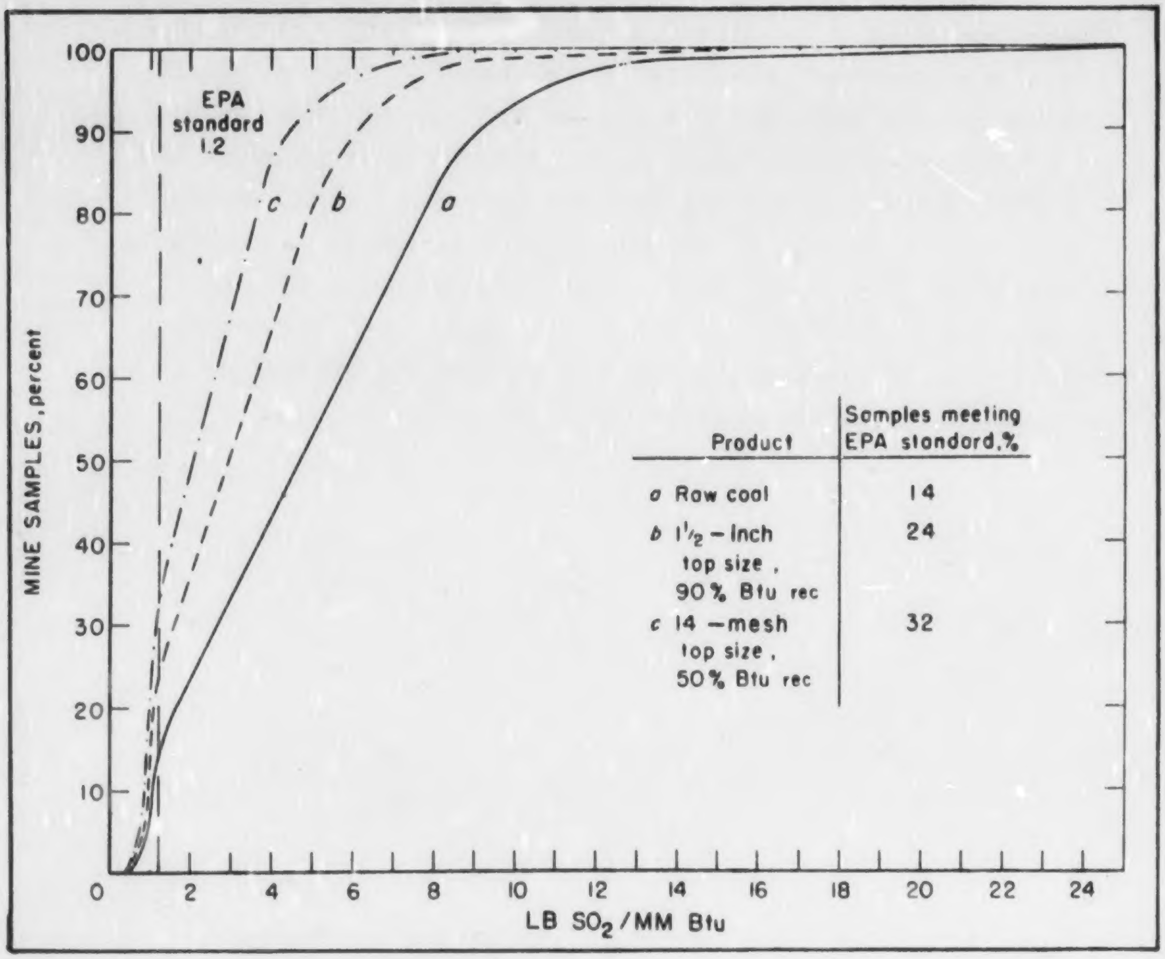


Figure 14-5

Percent of All U.S. Coal Samples Meeting the Current EPA Standard of 1.2 Pounds SO_2/MM Btu with no Preparation, Curve a; Compared With Those Crushed to 1½ inch Top Size at a Btu Recovery of 90 Percent, Curve b; and Those Crushed to 14 mesh Top Size at a Btu Recovery of 50 Percent, Curve c, and Separated Gravimetrically.

> Twenty-four percent of the samples would meet the standard at a 90 percent Btu recovery when crushed to 1½ inch top size, while 32 percent would meet the standard at a Btu recovery of 50 percent when crushed to a 14-mesh top size.

The composite data (Table 14-1) show if all the coals were upgraded at a specific gravity of 1.60, the analyses of the clean coal products of the various regions would range on the average from 5.1 to 8.3 percent ash, 0.10 to 1.80 percent pyritic sulfur, 0.56 to 3.59 percent toal sulfur, 12,799 to 14.264 Btu per pound and would produce 0.95 to 5.5 pounds of SO_2/MM at Btu recoveries ranging from 91.7 to 97.6 percent. The corresponding SO_2/MM removal efficiencies required to comply with the current EPA emission regulations of 1.2 pounds SO_2/MM Btu would range from 0 to 78 percent.

REFERENCES AND/OR ADDITIONAL READING

AMAX Henderson, "An Experiment in Ecology", Editorial Alert - 1974, Mountain Empire Publishing Company

American Society for Testing Materials, "Standard Methods for (1) Collection of a Gross Sample of Coal, (2) Preparing Coal Samples for Analysis", Part 19

Bituminous Coal Research, Inc., "An Evaluation of Coal Cleaning Processes and Techniques for Removing Pyritic Sulfur from Fine Coal", BCR Report L-339, September 1969, BCR Report L-362, February 1970, BCR Report L-404, April 1971, BCR Report L-464, April 1972

Bluck, W.V. & Norton, G., "High Intensity Fine Coal Flotation", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

British Coke Research Association, "Methods for the Float and Sink Analysis of Coal (Technical Paper No. 3)", London, England, January 1952

Brobst, Donald A. & Pratt, Walden P. (Editors), "United States Mineral Resources", Geological Survey Professional Paper 820, U.S. Government Printing Office, 1973

Burdon, R.G.; Booth, R.W.; Mishra, S.K., "Factors Influencing the Selection of Processes for the Beneficiation of Fine Coal", Australia, Australian Coal Conference

Carter, R.P.; Wilkey, M.L.; Johnson, D.O.; Kennedy, A.S., "Coal Blending as a Means to Meet Air Emission Standards", NCA/BCR Coal Conference and Expo II, October 1975

Casali, J.T., "Heat Drying Sludge from Ponds", American Mining Congress Coal Convention, May 5-8, 1974

Cassady, Jon M., "Obstacle Course for Permits and Approval", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Cavallaro, J.A.; Deurbrouck, A.W.; Baker, A.F., "Physical Desulfurization of Coal", Alche Symposium Series, Vol. 70, pp. 114-122

Cavallaro, J.A.; Johnston, M.T.; Deurbrouck, A.W., "Sulfur Reduction Potential of the Coals of the United States", U.S. Bureau of Mines RI 8118

Chemical Construction Corporation, "The High Sulfur Combustor--Volume I", National Technical Information Service, Springfield, Virginia, February 1971

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Coal Age, "The Coming Surge in Coal Preparation", January 1976

Coal Age, "Multi-Stream Coal Cleaning System Promises Help With Sulfur Problem", January 1976

Colorado School of Mines, "Removal of Sulfur from Coal by Treatment with Hydrogen--Phase I", Research and Development Report #77, Interim Report No. 1

Cuffe, Stanley T., et al., "Emissions from Coal-Fired Power Plants", National Technical Information Service, Springfield, Virginia, 1967

Cutler, Stanley, "Emissions from Coal-Fired Power Plants", U.S. Department of Health, Education and Welfare, 1976

Dancy, T.E., "Control of Coke Oven Emissions", AISI Yearbook, p. 181, 1970

Day, James M., "Current Status of Proposed Federal Waste Disposal Rules", Mining Congress Journal, June 1974

Dell, C.C.; Jenkins, B.W., "The Leeds Flotation Column", United Kingdom, Australian Coal Conference

Deurbrouck, A.W.; Jacobsen, P.S., "Coal Cleaning -- State-of-the-Art", Coal Utilization Symposium - SO_2 Emission Control, Coal and the Environment Technical Conference, National Coal Conference, October 1974

Deurbrouck, A.W., "Sulfur Reduction Potential of the Coals in the USA", U.S. Bureau of Mines Report of Investigations #7633, 1972

Deurbrouck, A.W., "Survey of Sulfur Reduction in Appalachian Region Coals by Stage Crushing", U.S. Bureau of Mines Report of Investigations #8282

Doyle, Frank J.; Bhatt, H.G.; Rapp, J.R., "Analysis of Pollution Control Costs", Report prepared for Appalachian Regional Commission and Office of Research and Development of the EPA, EPA 670/2-74-009, February 1974

Doyle, F.J.; Blatt, H.G.; Rapp, J.R., "Analysis of Pollution Control Costs", EPA 670/2-74-009

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Ellison, William; Heden, Stanley D.; Kominek, Edward G., "System Reliability and Environmental Impact of SO_2 Processes", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Engdall, R.B., "A Critical Review of Regulations for the Control of Sulfur Oxide Emissions", Battelle Columbus Laboratories, APCA Journal Vol. 23, #5, May 1973

Environmental Analysis, Inc., "Air Quality in Nassau-Suffolk County, N.Y.", 1972

Environmental Protection Agency, "Air Pollution Emission Factors", EPA Publication AP-42, April 1973

Environmental Protection Agency, "Air Pollution Technical Publications of the Environmental Protection Agency, Research Triangle Park, North Carolina, July 1974

Environmental Protection Agency, "Environmental Impact Assessment Guidelines for Selected New Source Industries"

Falkenberry, Harold L., "Emission Controls--Status at Coal Burning Power Plants", Mining Congress Journal, May 1973

Federal Register, "Standards of Performance for New Stationary Sources (Coal Preparation Plants)", Volume 39, #207, Part II, EPA, October 24, 1974

Gayle, J.B.; Eddy, W.H., "Effects of Selected Operating Variables on Continuous-Cell Flotation of Coal: A Lab Study", U.S. Bureau of Mines Report of Investigations #5989

Gayle, J.G.; Smelley, A.G., "Selectivities of Laboratory Flotation and Float-Sink Separations of Coal", U.S. Bureau of Mines Report of Investigations # 5691, 1960

Geer, M.R.; Jacabsen, P.S.; Sokasi, M., "Dewatering Coal Flotation Tailing by the Admixture of Crushed Washery Refuse", U.S. Bureau of Mines Report of Investigations #7110

Goodrich, John C., "Computer Mapping of Coal Reserves by Sulfur Level", Harvard University, Cambridge, Massachusetts, April 1971

Graham, H.G.; Schmidt, L.D., "Methods of Producing Ultra-Clean Coal for Electrode Carbon in Germany", U.S. Bureau of Mines IC-7481, October 1948

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Hall, A.W.; Martin, J.W.; Stewart, R.F.; Poston, A.M., "Precision Tests of Neutron Sulfur Meter in Coal Preparation Plants", U.S. Bureau of Mines Report of Investigations #8038, 1975

Hand, John W., "Drying of Western Coal", Mining Congress Journal, May 1976

Helfinstine, R.J., et al., "Sulfur Reduction of Illinois Coals--Washability Studies, Phase II", Illinois State Geological Survey, July 1971

Henderson, G.S.; Andren, A.W.; Harris, W.F.; Reichle, D.E.; Shugart, H.H.; Van Hook, R.I., "Environmental Assessment of SO_2 and Trace Element Emissions from Coal Utilization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Henderson, James, "Environmental Overkill the Natural Resource Impact", American Mining Congress Convention, October 1974

Hill, George R., "Clean Fuels from Coal--The OCR Challenge", Mining Congress Journal, February 1973

Hoffman, L.; Truett, J.B.; Aresco, S.J., "An Interpretative Compilation of EPA Studies Related to Coal Quality & Cleanability", Mitre Corporation, May 1974, EPA 650/2-74-030

Hoffman, L. et al., "Survey of Coal Availability by Sulfur Content", Mitre Corporation, May 1972

Hollinden, Gerald A.; Elder, Henry W., "Worldwide Review of Major Sulfur Dioxide Removal Processes Applicable to Coal-Fired Utility Boilers", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Hulett, L.D.; Carter, J.A.; Cook, K.D.; Emery, J.F.; Klein, D.H.; Lyon, W.S.; Nyssen, G.A.; Fulkerson, W.; Bolton, N.E., "Trace Element Measurements at the Coal-Fired Allen Steam Plant--Particle Characterization", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky 1974

Iooss, R.; Labry, J., "Treatment of Ultra-Fine Material in Raw Coal In the Provence Coalfield", France, Australian Coal Conference

Irminger, P.F.; Giberti, R.A., "Desulfurization Technology to Meet the Power Demand", NCA/BCR Coal Conference and Expo II, October 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Jimeson, R.M.; Spindt, R.S., "Pollution Control and Energy Needs", Advances in Chemistry Series, American Chemical Society, Washington, D.C., 1973

Jonakin, J., "Solving the SO_2 Problem--Where We Stand with Application and Costs", Coal Age, May 1975

Journal of the Air Pollution Control Association, "Panel Calls Beneficiation-FGD Combination 'Most Economical, Best All-Around Choice'", November, 1975

Kennecott Copper Corporation, "Chemical Desulfurization of Coal", American Mining Congress Coal Convention, May 508, 1974

Kent, James A. (Editor), "Riegel's Handbook of Industrial Chemistry (7th Ed.)", Van Nostrand Reinhild Publishing Company, New York, 1974

Kester, W.M., "Magnetic Demineralization of Pulverized Coal"

Kilgroe, James D., "Physical and Chemical Coal Cleaning for Pollution Control", Industrial Environmental Research Laboratory, Environmental Protection Agency, Research Triangle Park, North Carolina

LaMantia, Charles R.; Raben, Irwin A., "Some Alternatives for SO_2 Control", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Lawrence, William F.; Cockrell, Charles F.; Muter, Richard, "Power Plant Emissions Control", Mining Congress Journal, April 1972

Leavitt, Jack M., Leckenby, Henry F.; Blackwell, John P.; Montgomery, Thomas L., "Cost Analysis for Development and Implementation of a Meteorologically Scheduled SO_2 Emission Limitation Program for Use by Power Plants in Meeting Ambient Air Quality SO_2 Standards", TVA Air Quality Branch, Marcel Dekker, Inc., 1974

Leonard, Joseph; Mitchell, David, "Coal Preparation", American Institute of Mining, Metallurgical and Petroleum Engineers, Inc., 1968

Lewis, Clifford J., "Development of a Rotating Stack Gas Scrubber", NCA/BCR Coal Conference and Expo II, October 1975

Lowman, Stephen G., "Westmoreland Coal's Bullitt Plant Upgrades Steam Coal Quality", Coal Age, 1973

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Lowry, H.H. (Editor), "Chemistry of Coal Utilization", John Wiley & Sons, Inc., New York, New York, 1963

Lovell, Harold L., "Sulfur Reduction Technologies in Coals by Mechanical Beneficiation (3d Draft)", Commerce Technical Advisory Board Panel on SO_2 Control Technologies, March 1975

Luckie, Peter T.; Draeger, Ernie A., "The Very Special Considerations Involved in Thermal Drying of Western Region Coals", Coal Age, January 1976

Magee, E.M. et al., "Evaluation of Pollution Control in Fossil Fuel Conversion Processes; Gasification; Section 1: Koppers-Totzek Process", EPA Project 69-02-0629

Magee; Hall; Varga, "Potential Pollutants in Fossil Fuels", Environmental Protection Technology Series, ESSO Research & Engineering Company, June 1973

Markley, R.W.; Cavallaro, J.A., "Efficiency in Cleaning Fine Coal by Froth Flotation--A Cell by Cell Pilot Plant Evaluation", Mining Congress Journal, June 1974

Martinka, Paul D.; Blair, A. Ross, "Western Coal Transportation - A Challenge", American Mining Congress Convention, October 1974

Massey, Lester G., "Coal Gasification", Advances in Chemistry Series, American Chemical Society, Washington, D.C. 1974

McNally-Pittsburg Manufacturing Corporation, "Coal Cleaning Plant Prototype Plant Design Drawings", Department of Health, Education and Welfare Contract 22-68-59

Mesko, J., "Atmospheric Fluidized Bed Steam Generators for Electric Power Generation", 36th Annual Meeting of American Power Conference, 1974

Meyers, Sheldon, "The Development of Coal Resources and the Environmental Impact Statement", Coal Utilization Symposium-Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Miller, Kenneth J., "Coal-Pyrite Flotation: A Modified Technique Using Concentrated Second-Stage Pulp", U.S. Bureau of Mines Coal Preparation Program, Technical Progress Report 91, May 1975

Miller, K.J.; Baker, A.F., "Electrophoretic - Specific Gravity Separation of Pyrite from Coal", U.S. Bureau of Mines Report of Investigations #7440

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Miller, K.J.; Baker, A.F., "Flotation of Pyrite from Coal", U.S. Bureau of Mine Technical Progress Report #51, February 1972

Miller, R.E.; Agarwal, J.G.; Petrovic, L.J., "Economic & Technical Considerations in the Use of Coal as Clean Fuel", American Mining Congress Convention, May 6-9, 1973

Mining Congress Journal, "Pilot Plant for Solvent Refining of Coal" January 1973

Montgomery, T.L.; Frey, J.W., "Tall Stacks and Intermittent Control of SO_2 Emissions TVA Experience and Plans", American Mining Congress Convention, October 1974

Nandi, S.P.; Walker, P. L., Jr., "Absorption Characteristics of Coals and Chars", National Technical Information Service, Springfield, Virginia, April 1972

National Coal Association, "Coal Makes the Difference", 56th National Coal Association Convention, June 1973

National Coal Association, "Coal Utilization Symposium--Focus on SO_2 Emission Control", Coal and the Environment Technical Conference, October 1974

National Coal Association, "Second Symposium on Coal Utilization", NCA/BCR Coal Conference and Expo II, October 1975

Norton, Gerry; Bluck, Willard V., "A High Intensity Fine Coal Flotation Cell", American Mining Congress Coal Convention, Pittsburgh, Pennsylvania, May 1975

Norton, Gerry; Symonds, D.F.; Zimmerman, R.E., "Yield Optimization in Process Plan Economics", AIME Annual Meeting, New York, New York, February 1975

O'Brien, Brice, "Environmental Protection", Mining Congress Journal, February 1974

O'Hara, J.B.; Ripper, S.N.; Loran, B.I.; Mindheim, W.I., "Environmental Factors in Coal Liquification Plant Design", EPA Symposium on Environmental Aspects of Fuel Conversion Technology, May 1974

Ottmers, Delbert M.; Phillipps, James L.; Sipes, Teresa G., "Factors Affecting the Application of Flue Gas Desulfurization Systems to Gas- and Oil-Fired Power Plants Being Converted to Coal-Fired Units", NCA/BCR Coal Conference and Expo II, October 1975

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Padgett, Joseph, "Sulfates--Recent Findings and Policy Implications", NCA/BCR Coal Conference and EXPO II, October 1975

Paul Weir Company, Inc., "An Economic Feasibility Study of Coal Desulfurization", Chicago, Illinois, October 1965

Phelps, E.R., "Federal Coal Leasing Policy", American Mining Congress Convention, October 1974

Poland, "Beneficiation of Coal Fines by Selective Flocculation", Australian Coal Conference

Quig, Robert H., "Chemico Experience for SO_2 Emission Control on Coal-Fired Boilers", Coal Utilization Symposium--Focus on SO_2 Emission Control, Louisville, Kentucky, October 1974

Resource Planning Associates, Inc., "Energy Supply/Demand Alternatives for the Appalachian Region--Executive Summary", Council for Environmental Quality, Appalachian Regional Commission and the National Science Foundation, Report EQ-022, March 1975

Roberts & Schaefer Company, "Design & Cost Analysis Study for Prototype Coal Cleaning Plant", August 1969

Rubin, E.S.; MacMichael, F.C., "Impact of Regulations on Coal Conversion Plants", Environmental Science & Technology, 9, 112, 1975

Sage, W.L., "Combustion Tests on a Specially Processed Low-Ash, Low-Sulfur Coal", National Technical Information Service, Springfield, Virginia, 1964

Sableski, Joseph J., Jr.; Sedman, Charles B.; Jones, Larry G., "Development of Standards of Performance for New Coal Preparation Plants", Mining Congress Journal, October, 1972

Saleem, A., "Commercial SO_2 Removal at Detroit Edison Using Limestone in a High Velocity Spray Tower", Coal Utilization Symposium-Focus on SO_2 Emission Control, Lousville, Kentucky, October 1974

Schaeffer, Stratton C.; Jones, John W., "Coal Preparation vs. Stack Gas Scrubbing to Meet SO_2 Emission Regulations", NCA/BCR Coal Conference and Expo II, October 1975

Soderberg, H.E., "Environmental Energy & Economic Considerations in Particulate Control", American Mining Congress Coal Convention, May 5-8, 1974

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Stacy, W.O.; Walker, P.L., Jr., "Structure and Properties of Various Coal Chars", Pennsylvania State University, National Technical Information Service, Springfield, Virginia, September 1972

Stoev, St.; Krasteva, K., "Coal Preparation by Reverse Stratification", Bulgaria, Australian Coal Conference

Tompos, E., "Detailed Investigation of Pyrites Distribution, Taking Account of the Petrographic Components of Coal, with a View to Reducing the Pyrites Content in Coking Coal", Hungary, Australian Coal Conference

Tyler, C.E., "Testing Sieves & Their Uses", Combustion Engineering, Inc. Handbook #53, 1973 Edition

U.S. Bureau of Mines, "Clean Energy from Coal Technology", Overview of Coal/Energy Usage, U.S. Government Printing Office, 1974

U.S. Bureau of Mines, "Coal--Bituminous and Lignite in 1973", Division of Fossil Fuels, U.S. Department of Interior Mineral Industry Surveys, January 1975

U.S. Bureau of Mines, "Commodity Data Summaries - 1976"

U.S. Bureau of Mines, "Methods of Analyzing and Testing Coal and Coke", Bulletin 638, Office of the Director of Coal Research, 1967

Vasan, Srini; Willett, Howard P., "Alternate Desulfurization Techniques For Coal Gasification Projects", NCA/BCR Coal Conference and Expo II, October 1975

Volsicky, Z.; Puncmanova, J.; Hosek, V.; Spacek, F., "Bacteriological Leaching-Out of Finely Intergrown Sulfur in Coal: Method and Features", Czechoslovakia, Australian Coal Conference

Warnke, W.E., "Latest Progress in Sulfur, Moisture and Ash Reduction Coal Preparation Technology", American Mining Congress Coal Convention, Detroit, Michigan, May 1976

West Virginia Geological & Economic Survey, "Suitability of West Virginia Coals to Coal Conversion Processes", Coal-Geology Bulletin No. 1, December 1973

Yenovsky, A.Z.; Remesnilsov, I.D., "Thermomagnetic Method of Concentrating and Desulfurizing Coal"

REFERENCES AND/OR ADDITIONAL READING
(Continued)

Zitting, Richard T., "Solid Fuels: Their Contribution to Energy Independence", American Mining Congress Convention, October 1974

APPENDICES

APPENDIX 1

GLOSSARY OF SELECTED TERMS

Abatement	- A statement of the reduction of pollution effects of mine drainage.
Abrasiveness	- Abrasiveness is the ability of coal to cause wear and is significant because it increases costs. The ash content of a coal causes most of the wear.
Abutment	- The point of contact between the ends of an embankment and the natural ground material is called the abutment.
Acid Producing Materials (Acid Forming)	- Usually, rock strata containing significant pyrite which if exposed by coal mining will, when acted upon by air and water, cause acids to form.
Acid Mine Drainage	- Any acid water draining or flowing on or having drained or flowed off, any area of land effected by mining is called acid mine drainage (AMD).
Acid Soil	- Generally, a soil that is acid throughout most or all of the parts of it that plant roots occupy is referred to as acid soil, commonly applied to only the surface-plowed layer or some other specific layer or horizon of the soil. Practically, this means a soil with a pH less than 6.6; precisely, a soil with a pH less than 7.0. Alternately, a soil having a preponderance of hydrogen or hydroxyl ions in the soil solution may be referred to as acid.
Acid Spoil	- The spoil or waste material containing sufficient pyrites so that the weathering produces acid water and where the pH of the soil determined by standard methods of soil analysis is between 4.0 and 6.9.
Acre-Foot	- A term used in measuring the volume of water, equal to the quantity of water required to cover 1 acre x 1 foot in depth, or 43,560 cubic feet.

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Aquifer - A water bearing formation through which water moves more readily than it can through an adjacent formation with lower permeability.

Ash Balance - Ash balance is a method for estimating the amount of one of the products or the feed to a unit process or an entire operation by means of known ash percentages for each. The process is analogous to conservation of matter and may be thought of as "conservation of ash."

Ash Constituents - The principal contributors to coal ash are the following mineral groups: the shale group, the kaolin group, the sulfide group and the carbonate group. Most ash constituents are present as silicates. The most abundant oxides present in coal ash are silica (SiO_2), aluminum oxide(Al_2O_3), ferric oxide (Fe_2O_3) and calcium oxide (CaO).

Ash Content - Ash content of a coal is inorganic residue remaining after ignition of combustible substances, and is determined in the proximate analysis of a coal sample. After the moisture of the sample is established, the weight of ash is found by placing the sample in a cool electric muffle furnace and gradually increasing the temperature to 700 to 750°C and holding this temperature for 10 to 15 minutes until all the carbon has burned off. Then the ash is weighed and ash percentage (%A) is determined according to the following:

$$\%A = \frac{\text{weight of ash}}{\text{weight of sample}} \times 100$$

Ash Error - Ash error indicates the difference between the ash content of the clean coal product and the theoretical ash from the washability data at the same yield.

Ash Fusion Temperature - Ash fusion temperature is the temperature at which the ash of a coal softens or fuses. If the ash fuses at a comparatively low temperature, it may cause clinkering or slagging when the coal is burned. The ash fusion temperature is found by heating a cone made from ash of the given coal in a furnace where the temperature can be gradually increased. The ash softening temperature is that temperature at which the ash becomes a spherule, and is read using an optical pyrometer, or with a suitably place thermocouple.

Ashline - A relationship between specific gravity and percent ash of a coal. This information, which is used to accomplish curve fitting, is at the present time largely determined by experience. It supplements actual test data or specified data to aid in determining smaller increments, for use in calculations, by interpolating or extrapolating from the given points.

Blinding - Blinding is a term describing the lodging of pieces of coal or slate in the bed of material being carried on a screen deck which results in a decrease in open area for the particles to pass through the screen surface.

Breaker - A breaker is often called a "rotary breaker." It is a rotating drum type coal crushing machine with internal lifting vanes, and with holes in the drum shell which pass the largest size of coal desired. The coal is broken by impact inside the drum in dropping from the lifting vanes. An important feature of the breaker is that undesirable ash producing rock and shale is often tougher than coal and discharges with other unbreakables. The unbreakables, timbers, tramp iron, etc., are discharged from the end of the drum away from the feed and this helps to reduce the refuse load and nuisance load in the remainder of the preparation process. The breaker is commonly the first process piece of equipment in the preparation plant.

Btu - One Btu is defined as the amount of heat required to raise the temperature of one pound of water one degree Fahrenheit.

Btu Value - Btu value, also known as the calorific value or heating value, is usually expressed for a solid fuel as Btu per pound of fuel. This Btu may be based on an "as received," a "dry," or a "moisture and ash-free" basis and the basis should always be stated. It is the heat of combustion of a substance as determined by test using an oxygen bomb calorimeter.

Bulk Density - Bulk density is the weight per unit volume of aggregates of materials. The usual units of bulk density are pounds per cubic foot (PCF). This includes the weight of the moisture in the aggregate. The solid material must necessarily be in pieces and air fills the voids in the aggregate volume.

The bulk density is significant -- though generally of a somewhat different value -- with material in a container or free standing, or with the material suspended in a stream of air, or with material in motion. In motion the materials again can show different bulk densities when in free fall, traveling down chutes, or with different methods of conveying. Reducing the moisture content of coal, for example, can sometimes increase the bulk density and coarser coal often has a higher bulk density than finer coal. A common bulk density used for coal is 50 PCF whereas the solid density of the coal might be about 90 PCF. The solid density of coal is usually described as "specific gravity" to help eliminate confusion in the type of density being considered.

Classification - Classification is a "sizing" process where the effects of specific gravity of the particles is a factor in the separation. When a sizing is carried out on screens the particle must pass through a given hole size and thus particle dimensions are of primary importance. Classification, in contrast, is usually a solid-particle-in-a-fluid sizing process where heavy fine particles can join lighter coarse particles. In the classification process, if the particles are all of the same specific gravity, a pure size separation is possible. Also some classification devices can be designed or adjusted to minimize specific gravity phenomenon to give a result closer to pure size separation. Particle shape is also a factor in both screen sizing and classification of particles in fluids. Generally particle shape is of somewhat secondary importance and shows up in other measured variables.

Classifier or Classifying Cyclone - A classifier cyclone is used as a hydraulic centrifuge or thickening slurry solids. The overflow is controlled by an overflow valve, and the size of both overflow and underflow orifices. Normally the underflow volume is about 10 percent of the feed volume. By closing down the overflow valve a back pressure is applied, forcing more flow out the underflow. This lowers the classification point, which is the particle size of a material that is distributed equally between the overflow and the underflow. Thus, the classification point is adjusted to cause separation to occur at different sizes.

Coefficient of Permeability - The rate of flow of a fluid through a unit cross section of a porous mass under a unit hydraulic gradient at a standard temperature is called the coefficient of permeability. The standard coefficient of permeability used in the hydrologic work of the United States Geological Survey is defined as the rate of flow of water at 60°F in gallons or millions of gallons a day, through a cross section of 1 sq. ft. under a hydraulic gradient of 100%.

Comminution - Comminution is reduction to a smaller size, accomplished either on dry coal or in aqueous pulp. Depending on the size of the material being comminuted, the operation is regarded as crushing or grinding. In general, coarser materials are crushed.

Compressive Strength - Compressive strength is defined as resistance of material to rupture under compression, expressed as force per unit area. The load-bearing ability of coal, especially in pillars, as well as its strength in crushing and grinding, are reflected by the various measures of compressive strength. There is a general relationship between the rank of a coal and its compressive strength. However, there is no single standard way to measure compressive strength because coal is not a homogeneous material. It contains random cracks, and a small sample taken from the coal-mine face into the laboratory does not necessarily reflect bed conditions of loading and strain.

Concentration - Concentration is the term applied to the amount of any substance occurring in a given amount of water--the common unit is parts per million (PPM) or miligrams per liter (mg/l).

Concentrating Table - The concentrating table employs the principle of flowing a mixture of coal and water over a series of riffles on a slightly tipped table which is oscillated rapidly to effect a separation of the coal by particle size and specific gravity. Essentially the table consists of a pair of steel frames upon which are mounted two rubber-covered decks and a drive mechanism. Each flat, rhomboid-shaped deck is approximately 17 feet long on the clean coal discharge side and 8 feet wide on the refuse discharge side. It is supported in an essentially horizontal plane, but is slightly declined so that water fed along the upper side will flow across the table surface and discharge along the lower clean coal side. The deck is attached to a differential-motion drive which gives it a quick-return conveying motion, moving material lying on the table surface away from the drive end. The drive motion is perpendicular to the short sides of the rhomboid. Attached to the rubber covering on the deck is a system of parallel rubber riffles which taper toward the refuse end of the table and run in the direction of the conveying motion. At one corner of the long diagonal and above the deck is a feedbox with a slotted bottom to spread the feed onto the deck. Beside the feedbox and by the upper, longer side of the deck is a trough having adjustable gates through which the flow of dressing water to the deck is distributed.

Cyclone, Wet Classifying - The cyclone makes use of the mechanical properties of a vortex to effect the separation of coal. A raw coal slurry enters a cylindrical chamber tangentially with a given velocity and spirals downward onto a conical section, forming a strong vortical flow. The larger and heavier particles move along the wall of the conical chamber and are discharged through the underflow opening known as the apex orifice. The lighter and smaller particles have less tendency to settle at the wall and are forced to the core of the vortical flow. A tube called the vortex finder is positioned coaxially in the cyclone and collects the particles that are forced to the core. This material is termed overflow.

Deep Cleaning - Deep cleaning is the cleaning of coal to maximize reduction of impurities, especially sulfur, within economic limitations and generally implied is that the specific gravity of separation is lower than in normal plant operation. This is done by crushing to finer sizes and cleaning with conventional equipment, placing emphasis on maximizing the sharpness of separation.

Degradation - Degradation is the term applied to the breakage of coal caused by weathering or handling.

Density - A synonym for specific gravity, which might be solid denisty, liquid denisty or an overall density of a composite of solids and liquids.

Density Control - The specific gravity of the circulating medium of a heavy media cyclone is monitored by a density control sensing device. Any deviation from the desired specific gravity causes an error signal to be sent to a control motor, causing an appropriate change in the feed rate of thickened medium to the medium sump. The amount of magnetite in this flow of thickened medium, then, compensates for the amount of water retained on the drained products. The automatic control system maintains suitable balances and, therefore, preserves the desired specific gravity of the medium.

Desliming - Desliming is the washing of micronsized particles from a product by passing it over a screen and subjecting it to water sprays.

Dewatering - Dewatering of coal is the removal of excess surface moisture.

Distribution - Distribution refers to the percentages of each density fraction of the raw coal which reports to the clean coal. Distribution has a different value, as a rule, for each density fraction and for each size range of the given density fraction.

Distribution Curve - This is sometimes called the partition curve. The distribution curve indicates for each specific gravity fraction, the percentage of the specific fraction which is contained in one of the products of the separation (e.g., the clean coal). The curve values are plotted against the mean density of the particular fraction. It is used as a measuring and design criterion for cleaning methods and equipment. A distribution curve may also be plotted for a size fraction in reference to a piece of sizing equipment though its main use is with separations which are a function of specific gravity.

Distribution Factor - This is sometimes called the partition factor. It is the percentage of a specific gravity (or size) fraction recovered in one of the products of the separation (e.g., the clean coal). It is a more general term than distribution number.

Distribution Number - The distribution number is an absolute value that gives the percentage of the raw coal specific gravity fraction which reports to the reject of a piece of cleaning equipment. Engineers in the

United States use distribution number for the percentage of the raw coal specific gravity fraction that reports to the clean coal.

Distribution Value - This can be a synonym for distribution number. See distribution number definition. Distribution value can refer to other numbers also, such as probable error, specific gravity of separation, imperfection and error area.

Draining - Draining is the removal of water and media from a product of a heavy medium sink and float separator by passing the product over a vibrating screen with openings too small to permit loss of product, but which will pass the media.

Electrostatic Properties (Electrostatics) - Electrostatics is the science of electric charges captured by bodies which then acquire special characteristics due to their retention of such charges. Dry coal particles acquire charges as they pass through a high-voltage field. They are then deflected from their natural falling path in accordance with the attraction or repulsion due to the influence of their retained charge as they pass other charged bodies.

Error Area - Error area is the area between the actual distribution curve obtained in practice, and a theoretically perfect distribution curve which indicates 100 percent of the raw coal lighter than the separating gravity going to washed coal and zero percent of the raw coal heavier than the separating graving going to washed coal. It is a measure of the total misplaced material to clean coal and refuse, and is a "sharpness of separation" criterion.

Ferric Iron - Ferric iron is an oxidized or high-valence form of iron (Fe^{+3}) responsible for the red, yellow, and brown colors in soils and water.

Ferrous Iron Ferrous iron is a reduced or low-valence form of iron (Fe^{+2}) imparting a blue-gray appearance to water and some wet subsoils on long standing.

Float-and-Sink Testing Float-and-sink testing is known more scientifically as specific-gravity analysis, and is based on the difference in specific gravity between coal and its associated impurities. The concept involved is simply to procure a valid sample and effect a series of separations on the basis of specific gravity differences. This is done by immersing the sample

Float-and-Sink Testing (continued) in a series of heavy liquids, starting at about 1.30 specific gravity, and incrementing up to about 2.00 specific gravity. The float material is drawn off the first heavy liquid and set aside for drying and weighing and the sink material is placed in the next higher gravity liquid for a similar separating process. When the float material products from each gravity fraction are separated and set aside and a final sink product is also set aside and dried, the products are weighed. These weights are converted into percentages of the total sample and reported. Then, the specific gravity fraction samples are analyzed for ash, sulfur, and any other chemical characteristics desired. The data obtained in the analysis of a raw coal is useful in predicting the amenability of that particular coal to upgrading by washing. If the clean coal and refuse of a washing operation are also subjected to specific gravity analysis, the data obtained is used to determine the distribution curve and associated sharpness-of-separation criteria.

Flotation, Froth - A mechanical/chemical process which is based on the selective adhesion of some solids in suspension to air bubles while other solids in the suspension selectively adhere to water. A separation occurs when finely disseminated air bubbles are passed through a feed-coal slurry. The clean coal adheres to the bubbles while other solids in the suspension the surface where the forming froth is skimmed off and dewatered. The refuse tends to stay in suspension. Reagents are used to enhance selectivity by establishing a hydrophobic or air-loving surface on certain solids (i.e., clean coal particles) while the other solids (i.e., refuse) are rendered hydrophilic or water-loving.

Flotation Cell, Froth - Flotation cells are of two basic types, pneumatic cells and mechanical cells. The prototype plant will be using a mechanical type of call known as a Fagergren cell. This Fagergren cell features a rotor-stator assembly for agitation and aeration of the pulp. The stator consists of cylindrical spacers mounted between two rings which are rigidly fastened to the tank. The rotor construction is similar to that of the stator, except that the upper and lower bladed impellers are mounted within the rings. The rotor is suspended on a short drive shaft and rotates within the stator. Pulp enters directly into the tank through a suitable opening.

Flotation Cell, Froth (continued)	The pulp is drawn by the impeller blades into the rotor. Rapid pulp displacement creates a partial vacuum which causes air to enter into the rotor through the standpipe. The air is dispersed through the pulp in the form of fine bubbles. In passing between the cylindrical spaces of the rotor and stator, the pulp-water-air-mixture is highly agitated, giving efficient aeration. The froth is removed by a rotating skimmer and the refuse is drawn off at the bottom of the tank.
Friability	- The complement of size stability, friability is the tendency toward breakage on handling. It is an indication of the strength of the coal, and also an indication of preparation cost per ton since this is a function of the number of particles per ton of feed. The greater the proportion of fines in the feed, the greater the expected total preparation cost.
Free Swelling Index (F.S.I.)	- "Free Swelling Index" value is also known as the "coke button" value. It is determined using a simple test described in ASTM D720-67, "Free Swelling Index of Coal." The value obtained gives an approximate measure of the caking and coking characteristics of coal, but not of coal expansion properties in coke ovens. It is intended to describe the caking characteristics of a coal, or the opposite characteristic, free-burning. A one gram sample of minus 60 mesh coal is heated under prescribed conditions in a crucible and the resulting "button" is compared to a series of 17 button shapes ranging on a scale of values from 1 to 9, by halves. A match is made with one of the buttons on the scale and the number of that button is the F.S.I. value.
Grizzly	- A grizzly is a screen surface composed of parallel bars. The bars are usually tapered toward the discharge end to prevent clogging. Grizzlies are intended for coarse scalping and may be either fixed, movable or vibrating.
Hardgrove Grindability Index	Hardgrove Grindability Index (HGI) is used to determine a relative measure of the hardness of a coal. A special ring-and-ball-type grindability mill, as specified in ASTM D409-71 (see Appendix 8) is used to grind a 50 gram sample of 16 by 30 mesh coal for 60 revolutions. The sample is then sized at 200 mesh by 10 minutes of mechanical sieving.

Hardgrove Grindability Index (continued) The HGI number can be approximated using the equation HGI = 13+ 6.93 W, where W = (50 gm. - X), X being the weight of the material retained on the 200 M sieve. The 1971 revision of the method makes the exact index number a function on graphs determined from testing coals of known value on the given testing machine and accessories. (See "Rosin-Rammler plot" for relationship between HGI numbers and the slope of the screen analysis plot.) Higher index numbers represent softer, more breakable coal. The HGI number is lower for harder, less breakable coal.

Hardness - Defined by Hardgrove Grindability Index, hardness is a measure of the ease with which a coal may be made into a pulverized fuel. Thus, it is an indirect measure of the energy required to reduce a coal in size.

Heavy Media (H.M.) Cyclone - A heavy media cyclone employs centrifugal force on a coal in a heavy medium suspension, having a higher specific gravity than water, to effect a sharper separation between coal and impurity than can be obtained in other types of cleaners handling the same size range of coal. A suspension medium, of fine magnetite particles in water, carrying raw coal particles is fed to the heavy media cyclone. The clean coal reports to the overflow and the refuse material reports to the underflow. Separating concentration effects are maximized by use of a smaller cone angle than that of a hydrocyclone, 20° being about standard in the case of the heavy media cyclone.

Hydrocyclone The Hydrocyclone is a cyclone that does not employ an artificially higher specific gravity suspension but uses water only as medium for the coal. However, coal fines are generally accepted as contributing to a higher effective separating gravity. Design of the hydrocyclone differs from that of the conventional heavy medium cyclone by providing a much greater cone angle -- up to 120° -- and a longer vortex finder. Hydrocyclones are operated to suppress size classification phenomena in favor of specific gravity type concentration effects.

Imperfection Factor - The imperfection factor is equal to the probable error divided by a quantity equal to the specific gravity of separation minus the specific gravity of the separting medium. For jigs, tables, rheolaveurs and other washers the gravity of the separating medium, which is subtracted from the specific gravity of separation, is taken to be 1.

Independent Criteria (Coal washing) - The independent criteria are the performance criteria which are characteristic of the washing unit and which are substantially unaffected by the specific gravity composition of the raw coal are probable error, area error, and imperfection factor. They are commonly referred to as the sharpness-of-separation criteria.

Inherent Moisture - Bed moisture, as opposed to extraneous moisture, is termed inherent. The moisture content retained by the coal when in equilibrium with an atmosphere over a saturated solution of potassium sulfate at 30°C. is known as the equilibrium moisture of the coal. This atmosphere has a 96 to 97 percent relative humidity. When extraneous or free moisture is present in the coal, inherent moisture and equilibrium moisture may be considered to be the same. The inherent moisture is directly related to the rank of the coal.

Low Gravity Cleaning - The washing of coal at a specific gravity of separation of approximately 1.40 or lower.

Magnetic Properties - Those characteristics of coal and associated impurities which cause the particles to be attracted to, repelled from, or neutral to a magnetic pole are considered to be magnetic properties. These properties of coal can be utilized in a separation process using dry coal passing through a magnetic field.

Magnetite - Magnetite is a black isometric mineral (Fe_3O_4) of the spinel group that is an oxide of iron and an important iron ore. Having a specific gravity in the vicinity of 5, it can be ground to a fine size, and mixed with water to form a heavy media suspension to be used, for example, in heavy media cyclone circuits.

Mesh Size - Mesh size or, as it is sometimes called, "screen mesh size" have several standards. The most common standard in the coal industry is the "Tyler square-root-of-two series" and is the standard followed generally in U. S. research. ASTM specifications D 410, D 431, E 11 and E 323 which are listed in Appendix 8 include complementary mesh openings. ASTM standard E 11 contains the U.S.A. Standard Series. Where a specific series is called for in a particular procedure, as with the determination of the Hardgrove Grindability Index, or with proximate or ultimate analysis following ASTM procedures, where the U.S.A. Standard Series is specified, then such a specified series should be used.

Some sizes are designated by millimeters; e.g., ½ mm, 1 mm, 1.5 mm. These are ordinarily sizes which are used in dewatering or desliming. In these cases, long slotted openings of the stated opening width are commonly used. This opening size can be converted to a nominal mesh size, but it is not actually one, for a mesh size implies a square opening.

Also, sizes finer than 200 mesh are designated in microns. Screening below 200 mesh is something of a hypothetical process. Accurate actual screening is difficult at best although it is performed, and screening efficiency is very low for the screens readily blind. Thus the micron designation applies more to a mesh size by specifying a theoretical square opening which the actual particle would theoretically pass through. Micron size is also used in fine particle settling size designations. By suitable definition, the micron size characterization of a given particle should be very close in both cases.

The following is a size by size designation of the mesh sizes with the series to which a given mesh size refers. At 200 mesh (74 microns) both Tyler and U.S. Standard have the same opening size so this size is not included in the list.

Tyler Mesh Sizes	U.S. Standard Mesh Sizes
14 (1,168 microns)	8 (2,380 microns)
28 (589 microns)	16 (1,190 microns)
48 (295 microns)	30 (590 microns)
100 (147 microns)	60 (250 microns)

The figure in parenthesis in the above listing (xxx microns) is the opening dimension between wires of the particular mesh.

Metallurgical Coal - Coal which is suitable for coking and as coke has a high compressive strength. The coal usually has a maximum sulfur (about 1%) and a maximum ash content (about 10%) and naturally or by blending with a different coal will, in aggregate, behave as a medium volatile coal. A medium volatile coal is

Metallurgical Coal (continued) usually considered to have a volatile matter percentage in some range including 30 percent volatile matter.

Misplaced Material - Total misplaced material is that percentage of the feed which reports to the wrong product.

Near-Gravity Material - The amount of near gravity material is that percentage of material in the feed withing ±0.10 specific gravity units of the specific gravity of the separation. See the "Specific Gravity of Separation" definition below.

Organic Sulfur Content - See Sulfur.

Oversize - The oversize material is the material which stays on a given screen; i.e., not passing through the screen openings.

Performance Criteria - Performance criteria are the criteria that depend both on the washing characteristics of the coal being treated and on the sharpness of the separation achieved by the washer. These are also called dependent criteria, and include recovery efficiency, misplaced material, and ash error.

Petrographic Constituents - These are the constituents of coal discernible by miscroscopic examination. These constituents are important in determining coal rank and in carbonization studies. Coal petrography is a highly specialized field and extensive work has been done in regard to recognizing and naming petrographic components; and in correlating coal characteristics with these components.

Porosity - Porosity is the ratio "p" expressed as a percentage of the volume "Vp" of the pore space in a mineral to the total volume "Vr" of the mineral, the latter volume including mineral material plus pore space (coal is a mineral). $p = \frac{Vp}{Vr}$.

Prewetting Screen - A prewetting screen is a screen used in coal preparation ahead of a heavy medium separator to wash the fines from the material not removed by previous screening and to wet the surface of each particle before it enters the heavy medium bath.

Primary Dewatering Screen - A primary dewatering screen is a screen used in a coal preparation plant. It receives all the coal and water from the washer and may or may not be followed by further dewatering screens.

Primary Screen - A primary screen is a screen used in connection with heavy media processes. Its purpose is to remove fine sizes from the coal ahead of the separator. The screening is usually aided by using water sprays.

Probable Error - Probable error is obtained directly from the distribution curve and is numerically equal to one-half the specific gravity difference between the 25 and 75 percent washed coal recovery ordinates on the curve. It is frequently designated by the symbol "Ep".

Probable Maximum Flood - The most severe flood flow that would be expected to occur from the most critical hydrometeorological conditions that would be reasonable possible in a region. The occurrence of a flood of this magnitude would be highly improbable.

Proximate Analysis - Proximate analysis is a type of analysis of coal that has been in existence for many years. Proximate analysis is the determination, by prescribed methods, of moisture, volatile matter, fixed carbon (by difference) and ash. Details of a frequently used proximate analysis can be found in U.S. Bureau of Mines Bulletin 638, pp. 3-7. A similar analysis can be found as designated by ASTM but not specifically called "proximate analysis" in ASTM D271-68, "Laboratory Sampling and Analysis of Coal and Coke" Sections 6 through 17 under Methods of Analysis for Moisture, Ash, Volatile Matter and Fixed Carbon (Fixed Carbon by Difference).

Pulp - A slurry, but usually a slurry with more than one type of solid component.

Pulp Density - The percentage by weight of solids of a solids-water mixture.

Pyritic Sulfur - See Sulfur.

Rank - The rank of a coal expresses the degree to which the original coal-forming material has been changed by metamorphism through successive states from peat to anthracite.

Rapped Sieve Bend	- A rapped sieve bend is a sieve bend equipped with a rapping device. The rapping causes vibrations in the apparatus and thus tends to prevent blinding of the screen, thus allowing normal operation, (see Sieve Bend).
Raw Coal	- Raw coal is run-of-mine coal which has been reduced to a given top size by screening and crushing, and has not received other preparation.
Recovery Efficiency	- Recovery efficiency is defined as the ratio, expressed as a percentage, of the yield of washed coal to the yield of float coal of the same ash content shown to be present in the feed by the specific gravity analysis.
Recurrence Interval	- Recurrence interval (return period) is the average time between actual occurrences of a hydrological event of a given or greater magnitude.
Refuse	- Washed or separated waste material from the raw coal which was the object of the cleaning process. This material is also called "gob", "slate" or "hutch".
Rescreen	- Rescreen is the term applied to the screen used to remove the degradation product or undersized material from a product which has not been removed by prior screening operations.
Rinsing	- Rinsing is a term used to describe the use of water sprays over the screen deck to remove clay or other foreign substances, as employed in dense medium separation.
R.O.M. Coal	- "Run-of-Mine" coal is coal produced by mining operations before any preparation.
Rotary Breaker	- See Breaker.
Scalping	- Scalping is removing coarse, oversized material, usually ahead of a crusher or other primary process equipment to reduce the load on the specific process equipment.
Scrubber Screen	- A scrubber screen is a revolving screen with a scrubbing section of blank plates containing lifters to agitate the material.
Secondary Dewatering Screen	- A secondary dewatering screen follows a primary dewatering screen and dewaters and classifies the smaller sizes in a coal preparation plant.

Shaking Screens - Shaking screens are long screen bodies hung from flexible supports and supported by eccentrics. They have a long stroke at a relatively low speed.

Screening Efficiency - Screening efficiency is a rating percent figure used in describing a screening unit. The values used in the formula are determined by laboratory testing of actual feeds and products. In the reverse process, a given efficiency is frequently used in design and with proper selection is capable of ultimate verification after the installation is put into service. One measure of screening efficiency is the percent of the undersize in the feed that actually passes through the screening surface, or:

$$\text{Efficiency of Screen Undersize Recovery} = \frac{\text{\% of feed (or amount) which actually passes through screen surface}}{\text{\% of feed (or amount) which is undersize (should pass through screen surface)}}$$

Another generally recognized formula for screening efficiency is:

$$\text{Screen Efficiency} = \frac{\text{\% of feed (or amount) which is oversize on screening surface}}{\text{\% of feed (or amount) which actually passes over screening surface}}$$

Where: % true oversize in material passing over screen deck, as determined by testing sieves, where 100% represents all of the screen deck.

Shape Factor - Shape factor is that property of a particle which determines a relation between the particle surface area and the particle volume. It correlates with particle response to fluid type friction effects. The shape factor is equal to "one" for spheres. It is calculated by dividing the actual surface area of the particle, by the surface area of a sphere having the same volume as that of the particle. Various fluid frictional effects are involved throughout the many aspects of coal preparation. More specifically, they are present in screening and jigging, hindered settling, dust

Shape Factor (continued) collection, and in general anywhere that a particle must travel in a fluid or film.

Sharpness of Separation - The sharpness of separation for most cleaning devices diminishes with the increase in specific gravity of separation. It may be measured by an imperfection factor, which for jigs, tables and other equipment using water as a separating medium, is often taken as equal to the probable error divided by the specific gravity (from the distribution curve), minus the specific gravity of the separating medium. Later studies of the imperfection factor, as related to dense media vessels, indicate that a more constant imperfection factor value may be obtained by dividing the probable error by the specific gravity of the separation only. Imperfection factor thus tends to correct for the increase in probable error and results in a numerical figure that characterizes a particular cleaning device regardless of the separating gravity.

Sieve Bend - A sieve bend is a rigidly spaced and truly fixed screen used for preliminary sizing and dewatering of coal ahead of vibrating screens and centrifuges. It is a stationary, curved, wedge bar screen with the bars oriented at right angles across the line of flow.

Sieve Scale - A sieve scale is a list of apertures of successfully smaller screens and step sizing operation. The sieve ratio is the ratio of the aperture of a given screen and a given sieve scale to the aperture of the next finer screen.

Size Consist - Size composition or size consist is the specification of the percentage of coal, based on weight, in each size range. The size ranges must be stated. Size composition is a relative indication of the ease of degradation of a coal, which in turn is a function of friability, physical strength, and so on. Size consist is determined by a sieve analysis and may be expressed as a percentage between two sieve sizes or by accumulative percentages.

Sizing - Sizing is the process of dividing a mixture of grains of different sizes into groups or grade whose characteristic is the particles therein are more or less nearly the same size, that all have passed an aperture of certain dimensions and failed to pass through some smaller aperture.

Slurry	- A slurry is a suspension of solids in water. Coal slurries range between about 3 percent and 50 percent solids and are the form in which coal is fed to cyclones, hydrocyclones and flotation cells. Slurry frequently refers to a suspension of only one type of solid, such as raw coal in water.
Specific Gravity	- Specific gravity is the weight of a substance as compared to the weight of an equal volume of water. From the standpoint of coal preparation, it is the single most important physical property of coal. With the exception of froth flotation, all the methods of coal preparation in general use are dependent upon the difference in specific gravity between the desired coal and its associated impurities.
Specific Gravity of Separation	- The specific gravity of separation is read from the distribution curve at the 50 percent ordinate and is the specific gravity of material in the feed that is divided equally between clean coal and refuse.
Specific Gravity Units	- Specific gravity is described by a number, such as 1.5, which tells how much more an equal volume of the substance weighs compared to water, 50 percent or half again as much in the "1.5" case. This would be called 1.5 specific gravity units, and 1.6 would differ from 1.5 by 0.1 specific gravity units (S.G.U.).
Stacker	- A stacker is a heavy, usually rail mounted machine used to form material storage piles. The machine has a crane-like inclined boom that is sometimes at a fixed inclination but often can be raised or lowered to minimize dropping distance during operations. A belt conveyor is mounted on the boom to transport material from a receiving point, which may be from a moveable tripper on a feeding belt conveyor. A radial stacker has a fixed feed point which is also the pivot point about which the radial stacker rotates to form, in this case, a crescent shaped storage pile.
Stacker-Reclaimer	- A stacker-reclaimer is first of all a stacker. However, the boom belt conveyor is reversible and a rotating bucket wheel is mounted at the end of the boom to reclaim materials from the pile. With a stacker-reclaimer the boom must necessarily raise and lower and usually pivots around the stacker mode boom belt loading point also. The reclaimer

Stacker-Reclaimer (continued)	- function is controlled by an operator in a cab that travels with the stacker-reclaimer. Stacker-reclaimers usually travel in-line and are sometimes mounted on caterpillar tracks for additonal mobility.
Steam Coal	- This refers to virtually all coals that can be productively burned to produce steam in a boiler operation including lignite and what could otherwise be used as metallurgical coal. A very high ash coal (at say 70% ash) would not qualify. Coals with lower mositure and ash have more heating potential when burned.
Stratification	- Stratification is a term applied to the conditions that exist when the motion is applied to a material on a screen deck. The motion causes the finest particles to go to the bottom with each excessive larger size located in "stratis" or layers up to the top surface where the largest particles are.
Sulfur	- Sulfur occurs in coal in four basic forms; that is, native or free sulfur, as sulfate sulfur, as pyritic sulfur and as organic sulfur. Native or free sulfur is rare in coal and may be neglected when speaking about coal preparation. Weathering increases the percentage of sulfate sulfur in the coal. It is removed by normal wet coal preparation methods. Organic sulfur is a part of, and is linked with, the coal itself. The amount of organic sulfur present defines the theoretical lowest limit to which a coal can be cleaned for sulfur removal by physical methods. The percentage of organic sulfur in coal is determined by difference (not directly) from analyses. Finally, pyritic sulfur exists in two dimorphs of ferrous disulfide (FeS_2) that is as the minerals pyrite and marcasite. Pyritic sulfur is common to all coals and occurs both on the macroscopic and microscopic levels. It is determined directly from analyses and is the form of sulfur removed from coal by physical preparation methods.
Suspension	- A suspension is a system consisting of a solid dispersed in a liquid or gas, usually in particles of larger than colloidal size. The particles are mixed with but undissolved in the fluid. Solids dispersed in a solid are called "solid inclusions".
Total Misplaced Material	- Total misplaced material is the percentage of feed which reported to the wrong product. For sharp

separations, the misplaced material is that material having specific gravity values close to the specific gravity of separation and, thus, correlates with the amount of near gravity material.

Tramp Iron - Bolts, shovel teeth, picks and other uncrushable metal are termed tramp iron.

Trommel Screens - Trommel screens are similar to revolving screens except that they are carried on a thru-shaft instead of rollers.

Ultimate Analysis - Ultimate analysis supplies information on the elemental composition of coals in terms of ash, carbon, hydrogen, nitrogen, oxygen and sulfur. The analysis may be mde on an undried sample ("as-received" basis) or on a dried sample ("dry" basis). With the undried sample, the free moisture of the coal is reported as part of the hydrogen and as part of the oxygen. Thus ultimate analysis should always be specified as being on an as-received basis or on a dry basis. The analysis includes:

> the determination of carbon and hydrogen in the material as found in the gaseous products of its complete combustion, the determination of sulfur, nitrogen and ash in the material as a whole, and the estimation of oxygen by difference.

Details of a frequently used method of ultimate analysis can be found in U.S. Bureau of Mines Bulletin 638, pp. 3-5 for moisture and ash, and pp. 7-11 for carbon, hydrogen, nitrogen, sulfur and oxygen (oxygen by difference). A similar ultimate analysis will be found in ASTM D271-68, "Laboratory Sampling and Analysis of Coal and Coke". The procedure sections in the ASTM specification are: Section 6 through 11 for moisture and ash; Sections 18 through 25 for sulfur; and Sections 30 through 42 for carbon, hydrogen, nitrogen and oxygen. In both of the above ultimate analysis procedures, which are comparable, the ash and moisture in "proximate analysis" is the same ash and moisture used as part of the ultimate analysis.

Undersize - Undersize is a material that passes through a given screen opening.

Volatile Matter - A measure of the gases which are formed from coal on heating to a temperature around 950° C. in proximate analysis, but excluding moisture.

Washability Data	- The specific gravity fractions resulting from the specific gravity analysis of a coal are weighed and analyzed for ash and sulfur content and these three types of information provide the basis for calculating the washability data. The data are plotted as washability curves. The washability curves predict, for separation of the given coal at a given specific gravity: (1) percentage of the feed that will be recovered as clean coal, (2) the percentage of feed that will be refuse, (3) the ash analysis of the clean coal, (4) the ash analysis of the refuse and (5) the highest ash expected in the particular density fraction of the clean coal. Predictions for sulfur, as well as ash, can be included in sulfur analysis data is available, but these are not yet reliable.
Weir	- A weir is a notch over which liquids flow and which is used to measure the rate of flow. A dam across the stream for diverting or measuring the flow. (Note: The essential difference between an orifice and a weir is implicit in the expression: water flows through an orifice but over a weir.)
Yield	- Yield is also called "yield of coal" or "yield of washed coal". Yield is designated by the percent by weight of raw coal that reports to the clean process or to an equipment product. Sometimes the percent by weight of a certain feed coal that reports to a given process or equipment product is called yield, but then the feed and the product should be specifically designated.
Yield Error	- The difference between the yield of coal actually obtained and the theoretical yield at the ash content of the washed coal is termed yeild error.
Zeta Potential	- Zeta potential, or electrokinetic potential is the potential difference across an electric double layer, usually in a liquid next to a solid surface. The zeta potential concept is made evident in a phenomenon known and electrophoresis. Electrophoresis is defined by the migrating rate of electrokinetically charged particles which are suspended in a liquid, toward an electrode of opposite charge in a DC voltage (electrical force) field. Different particles typically have different rates of migration. The migration speed is directly proportional to the magnitude of the zeta potential of the particles and to the DC voltage

Zeta Potential (continued)	applied. The migration speed is inversely proportional to the distance between the electrodes. The potential is important in flocculation phenomenon, a factor to be considered in the flotation process and may be significant in other coal preparation equipment where individual particles are processed in fluids.

Site Number ___________

Date ___________

COAL-WASTE DISPOSAL INVENTORY QUESTIONNAIRE

We need your help to develop a complete and accurate coal-waste disposal inventory. Before completing the questionnaires enclosed in this folder, along with an aerial photograph of your site, please, read the following definitions and explanation.

DEFINITIONS

Site	A geographical location of past or present waste producing unit(s) such as a mine, mill, plant, and/or smelter and its associated waste disposal system or complex.
Disposal Area	A general area or plot of land within the site that is used as a place for long-term storing or disposing of waste materials
Waste Deposit	A structural entity consisting of a dump(s), an impoundment(s), or a combination of a dump(s) and/or impoundment(s) within a disposal area
Dump	A permanent or long-term accumulation of mine, mill, plant, and/or smelter waste materials, on or in the earth, not capable of impounding liquid
Impoundment	A depression; excavation; permanent or long-term accumulation of mine, mill, plant, and/or smelter waste materials; or other facility, on or in the earth, capable of impounding liquid; an impoundment includes: Retaining Elements--embankments, depressions, excavations, etc. Retained Elements--liquids, sludge, slurries, etc. Potential Retention--storage space able to retain liquids, sludge, slurries, etc.

EXPLANATION

Simple forms of coal-waste dumps and impoundments are illustrated inside this folder. Most of the more complex waste deposits are combinations and variations of the simple forms, but some complex forms defy categorization--these waste deposits are designated by type number VI if they are not capable of impounding liquid or sludge and by type number XI if they are capable of impounding liquid or sludge. (Use the back of the Basic Data Form, Section 1.4, for sketches of their plans and sections.)

Each site has been given an inventory number. In addition, at each site, waste deposits are numbered sequentially, with letters added to the numbers for simple forms that are combined into a structural entity. At the plant site shown in the aerial photograph on the back of this folder, for example, the ridge dump was numbered 01; the two side-hill dumps under the aerial tramway were numbered 02 and 03; the massive cross-valley structure was numbered 04 with the valley-fill dump at its upstream end designated 04-A, the three cross-valley impoundments designated 04-B, 04-C, and 04-D, and the side-hill dump along the right-hand side of the valley designated 04-E; the waste heap or stock pile alongside the railroad track was numbered 05; the two diked ponds beside the plant were numbered 06 and 07; and what may be a waste heap and/or ponds was numbered 08. Two small earth dams near the ridge-dump toe not shown in the photograph were numbered 09 and 10.

On the aerial photograph of your site in this folder, waste deposits have been classified by type and assigned numbers, with and without letters, as seemingly appropriate. We need to know: (1) if all of these waste deposits belong to your site, (2) if the classifications assigned them on the basis of the photograph are, indeed, reasonable ones, (3) if there are any other coal-waste deposits at your site, and (4) basic information about the structures.

Whether a simple form stands alone or in combination with other simple forms, a column in the Basic Data Form should provide information on each simple coal-waste deposit form at your site. Please, complete the Basic Data Form(s), Section 1.4, enclosed in this folder, providing the data called for in each box marked by a check. If any of the structures do not belong to your site, write "Not at this site" in its column, and indicate to whom it belongs. If there are other coal-waste deposits at your site, include them on the Basic Data Form by assigning numbers, letters, and type classifications and providing appropriate data in blank columns on the form.

Complete Section 2.0 for each column in the Basic Data Form, providing information on the dump or retaining element of the impoundment. Complete Section 3.0 for impoundments only, that is for each column in the Basic Data Form with a type number VII through XI. If information called for is the same for more than one structure at a site, refer to the earlier data by number and letter.

W A WAHLER
& ASSOCIATES 1023 CORPORATION WAY PALO ALTO CALIFORNIA 94303 • (415) 968 6250

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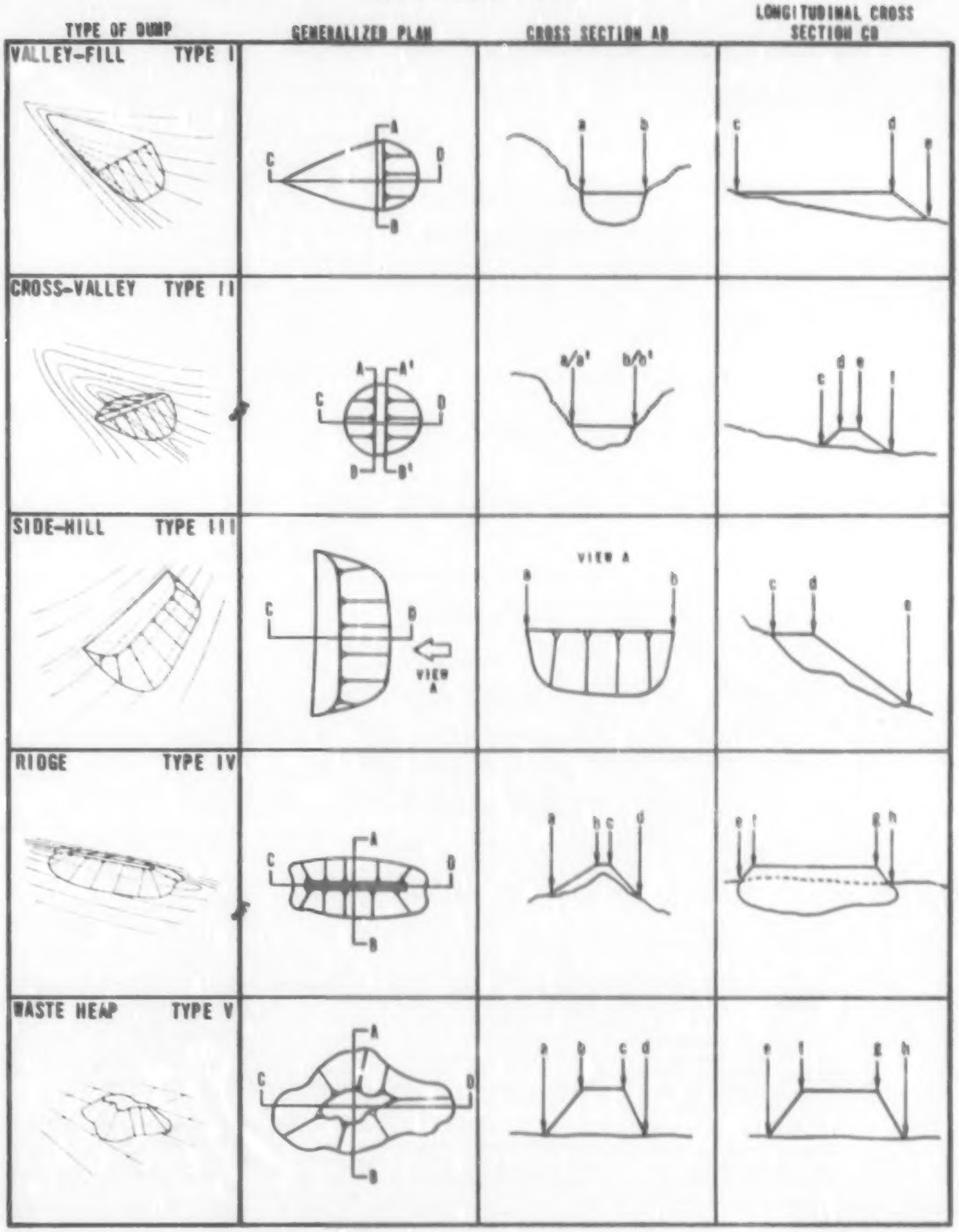
SIMPLE DUMP FORMS



Site Number ________
Date ________

1.0 OWNERSHIP AND SITE IDENTIFICATION

1.1 Site Name

site name

mailing address

city, state, zip

phone number

1.2 Physical Address

nearest town ________ county ________

____ miles from town ____ direction on road ____ number ________ state ________

1.3 Site Owner

Is the disposal area owned by the site operator? ____ yes ____ no

mine/plant owner name

mailing address

city, state, zip

phone number

parent organization

mailing address

city, state, zip

phone number

1.4 Basic Data Form

Whether a simple form stands alone or in combination with other simple forms, a column in the Basic Data Form, Section 1.4, should provide information on each simple coal-waste deposit form at your site. Please, complete the Basic Data Form(s) that are attached, providing the data called for in each box marked by a check. If any of the structures do no belong to your site, write "Not at this site" in its column, and indicate, if possible, to whom it belongs. If there are other coal-waste deposits at your site, include them on the Basic Data Form by assigning numbers, letters, and type classifications and providing appropriate data in blank columns on the form.

Complete Section 2.0 for each column in the Basic Data Form, providing information on the dump or retaining element of the impoundment. Complete Section 3.0 for impoundments only, that is for each column in the Basic Data Form with a type number VII through XI. If information called for is the same for more than one structure at a site, refer to the earlier data by deposit number and letter.

Site Number ____________

Date ____________

SECTION 1.4--BASIC DATA FORM

Provide the data called for in each box marked by a check. Number, letter, and classify and provide similar data for other coal-waste deposits at your site. Refer to sketches inside the folder for definitions of points.

Deposit Number								
Deposit Letter								
Type								
Elevations--ft msl or relative to downstream toe--two or more significant numbers								
a								
a'								
b								
b'								
c								
d								
e								
f								
g								
h								
Vertical Distances from Points to Foundation--ft--two or more significant numbers								
a								
a'								
b								
b'								
c								
d								
e								
f								
g								
h								
Horizontal Distances between Points--ft--three or more significant numbers								
ab								
a'b'								
bc								
cd								
de								
ef								
fg								
gh								
Berms-Slope								
Elevation								
Horizontal								
Slope								
Elevation								
Horizontal								
Maximum Storage Pond Area--acres								
Normal Storage Pond Area--acres								
Normal Water Depth at Embankment Face--ft								
Normal Sludge Depth at Embankment Face--ft								
Crest Shape--downstream arch, U-shaped, etc.								

W. A. WAHLER
& ASSOCIATES 1023 CORPORATION WAY PALO ALTO CALIFORNIA 94303 • (415) 968 6250

Site Number ____________
Deposit Number ____________
Deposit Letter ____________
Date ____________

SECTION 2.0

Complete for each column in the Basic Data Form, providing information on the dump or retaining element of the impoundment. If information called for is the same for more than one structure at your site, refer to the earlier data by deposit number and letter.

2.1 Name and Location

____
deposit name

______________________ ___ ° ___ ' ___ " ___ ° ___ ' ___ "
USGS 7.5' Quadrangle — north — west

2.2 Deposit Status

Same as ______ number ______ letter

Rate of past, present, and planned deposition from initiation to abandonment:

From-to (mo/yr)	______	______	______	______	______
Tons/day	______	______	______	______	______
From-to (mo/yr)	______	______	______	______	______
Tons/day	______	______	______	______	______

Is deposit burning or has it ever burned? ______ burning ______ burned ______ never burned ______ unknown

Is deposit being reworked or has it ever been reworked? ______ being reworked ______ reworked ______ never reworked ______ unknown

2.3 Deposit Foundation

Same as ______ number ______ letter

Describe type, structure, weathering, and drainage of the foundation:

____
____
____

Prior to construction, was foundation:	Pond			Embankment		
	Yes	No	Unknown	Yes	No	Unknown
Cleared of vegetation?	___	___	___	___	___	___
Stripped of overburden?	___	___	___	___	___	___

Are there any mines under the disposal area? Operating mine ____ Inactive mine ____ Abandoned mine ____ Potential mine ____ If so, how many feet below the waste deposit is it located? ______ If not, what is approximate distance to the nearest underground mine tunnel/drift? ________

If the deposit is or has been an impoundment, has the embankment been expanded in the upstream direction so that it may be partially founded on silt or sludge? ____ yes ____ no ____ unknown

2.4 Surficial Condition of Deposit

Same as ______ number ______ letter

	Yes	No
Are plants and/or trees growing on the deposit?	___	___
If so, do they have a normal attitude?	___	___
Are there any volcano-like boils on the deposit?	___	___

2.4 Continued

	Yes	No
Are there any sinkholes or other depressions on the deposit's surface?	___	___
Are there any surface cracks?	___	___
Is there any evidence of settlement?	___	___
Is there evidence of erosion?	___	___

If so, describe: ____

____

2.5 Deposit Movement

	Yes	No
Were settlement markers installed?	___	___
Is there any history of slope movement?	___	___

Is there any evidence of the following: Slides ____ Slumps _____
Flows _____ Bulges ______ Heaving ______ Loose/rolling rocks _____
Movement beyond the toe ______ ________________ ______________
other other

2.6 Consequence of Deposit Failure

	Yes	No
Is any property (railroad, highway, power line, etc.) threatened?	___	___
Is the deposit positioned so that if it were to slide or move it could block a watercourse?	___	___

	Number	None
Are any people working in a position directly threatened by potential slides or other movement?	______	____
Are any people living in a position directly threatened by potential slides or other movement?	______	____

2.7 Deposit Material and Source

What coal seams were or are being mined and what percent of each by volume is involved in this deposit:

Coal Seam	Other Name	Percent

What mining method(s) was or is being used?

____

About what percent by volume of the deposit is: Mine refuse rock ____ % Coal culm ____%
Mill refuse ____ % Red dog _____ % __________ ____ %
other

Which of the following equipment was or is being used to clean the coal?
Jigs ___ Air tables or cleaners ____ Flotation _____ Heavy media _____
Water tables _____ Wet cyclone _____ Dry cyclone _____ ____________ ______
other

2.8 Construction Method

	Spreading		Systematic Compaction					Same as
Deposition	Gravity	Mechanical	None	Refuse Only	Layers Clay	Layers Other	Unknown	
__ Aerial tram								number
__ Conveyor belt								
__ Dump truck								letter
______________								

Site Number ____________
Deposit Number ____________
Deposit Letter ____________
Date ____________

SECTION 3.0

Complete for each impoundment, that is for each column in the Basic Data Form with a type number VII through XI. If information called for is the same for more than one impoundment at your site, refer to earlier data by deposit number and letter.

3.1 Impoundment Status

Rate of past, present, and planned inflow from initiation to abandonment--

From wash plant:				
From-to (mo/yr)	________	________	________	________
Gallons/day	________	________	________	________
% Solids by weight	________	________	________	________
From mine drainage:				
From-to (mo/yr)	________	________	________	________
Gallons/day	________	________	________	________
% Solids by weight	________	________	________	________

Was embankment breached or is it to be breached upon discontinuation of impoundment operations? ____ yes ____ no

3.2 Outlet Facilities

Describe type, dimensions, location, and elevation (with respect to minimum embankment crest elevation) of:

Outlet conduits: ____________________

Open-cut spillway: ____________________

Diversion ditches: ____________________

Other outlet facilities: ____________________

If there is an open-cut spillway, is it cut into firm rock? ____ yes ____ no

If not, describe: ____________________

Describe downstream erosion protection: ____________________

Describe upstream erosion protection: ____________________

3.3 Seepage through the Embankment

Location of Seepage	None	Seep (0.1 gpm)	Trickle (1.0 gpm)	Flow (10 gpm)	Stream (10 gpm)
Right abutment contact					
Left abutment contact					
Foundation-toe contact					
Downstream shell					

If there is seepage on downstream face, what height is it above the toe?

_______ feet _______ feet _______ feet

Are there any visible sinkholes in impounded sludge? ____ yes ____ no

If so describe size and location: ______________________________

____

3.4 Impoundment Hydrology

Same as _______ number _______ letter

What is the approximate drainage area? _________ square miles

About what percent of the watershed is covered with vegetation? _______ %

devoted to commercial, industrial, or residential use? _______ %

stripped of vegetation for mining purposes? _______ %

otherwise stripped of or lacking vegetation? _______ %

3.5 Hydraulics and Consequences of Failure

Same as _______ number _______ letter

To complete the following table, use these character codes to describe downstream watercourse characteristics:

1 = improved channel section

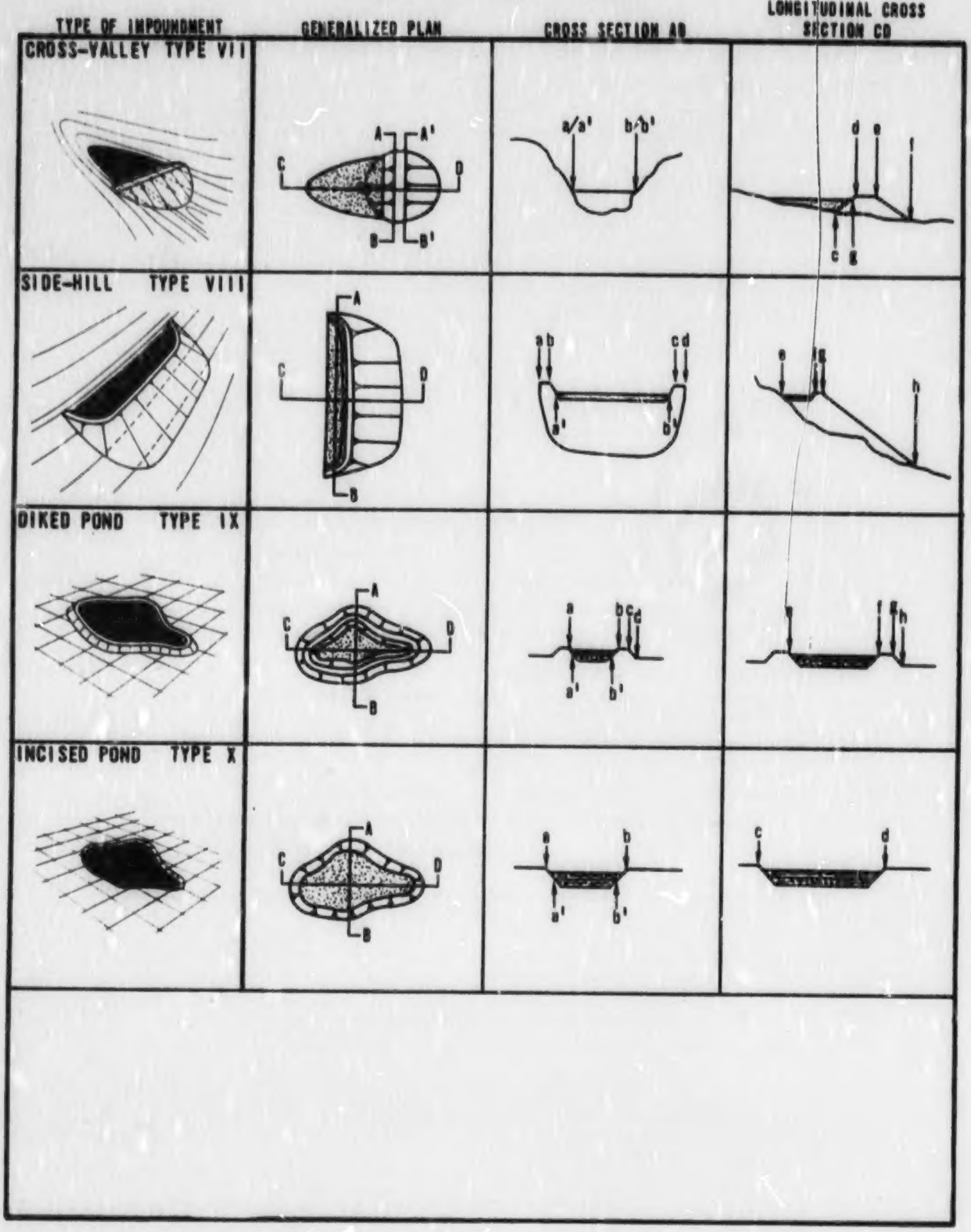
2 = well-defined confined natural channel

3 = reasonably well-defined and confined natural channel,

4 = poorly defined channel with extensive areas subject to overbank flooding

Character Code	Distance (mile) From	Distance (mile) To	Dimensions (feet)	Number on Flood Plain: Dwellings	Schools/ Churches	Com/Indus Establish	Other

SIMPLE IMPOUNDMENT FORMS



APPENDIX 3

Washability Curves and the Interpretation of Float-and-Sink Data

(Adapted from: G.D. Coe, An Explanation of Washability Curves For the Interpretation of Float-and-Sink Data on Coal, U.S. Bureau of Mines Information Circular No. 7045 (Washington: U.S. Department of the Interior Library, 1938), 10pp.)

A raw-coal sample is float-and-sink tested as described in Section V.D.2.d.). The Products resulting from the float-and-sink separations, after they have been dried, are weighed and analyzed for moisture and ash. The weights are calculated to percentages and the ash analyses to percentages on the moisture-free basis. These data are tabulated as shown in the first five columns of Table 1.

TABLE 1. - Arrangement of Float-and-Sink Data

Description (1)	Specific Gravity (2)	Weight Kg. (3)	Weight % (4)	Ash,[1/] % (5)	Cum. Weight % (6)	Cum. Ash,[1/] % (7)
Coal from the Pratt bed, Warrior Field, Alabama	Float on 1.27	5.10	34.5	2.8	34.5	2.8
	1.27 - 1.30	4.20	28.4	3.9	62.9	3.3
	1.30 - 1.38	2.50	16.9	8.8	79.8	4.5
	1.38 - 1.50	.79	5.4	16.9	85.2	5.3
	1.50 - 1.70	.48	3.3	30.6	88.5	6.2
	1.70 - 1.90	.45	3.0	46.2	91.5	7.5
	Sink in 1.90	1.25	8.5	71.3	100.0	12.9
		14.77				

[1/] Moisture Free basis

The values in Column 6, headed "Cumulative weight, percent," are in each instance the sum of all the preceding weight percentages. For example, the first value recorded in the "Cumulative weight, percent"

Pages 664 and 665 are blank.

column is the same as the first value in the "Weight, percent" column; the second value is the sum of the first two weight percentages; the third is the sum of the first three; and so on.

The values listed in column 7 of Table 1 have been computed and represent, in each instance, the ash analysis of the total float-coal on the corresponding specific gravity shown in column 2. For instance, the total coal floating at 1.27 specific gravity analyzed 2.8 percent ash; at 1.30 specific gravity, the cumulative ash analysis would be 3.3 percent at 1.38 the cumulative ash would be 4.5 percent; and so on. The last value, 12.9 percent, would be the analysis of the total coal sample, including the sink in the liquid of 1.90 specific gravity. The calculation of the cumulative ash percentage is based on the equation:

$$\frac{\text{"weight, percent" x "ash, percent"}}{100} = \text{units of ash}$$

where "units" means parts in the number of parts expressed by the corresponding weight percentage.

Referring again to the data of Table 1, the cumulative ash for the float-on-1.27 fraction is the same as the corresponding percentage listed under "ash, percent". The next cumulative ash value may be calculated in the following manner: In the float-on-1.27 fraction there is $\frac{34.5 \text{ x } 2.8}{100}$ or 0.9660 units of ash; in the 1.27-1.30 fraction there are $\frac{28.4 \text{ x } 3.9}{100}$ or 1.1076 units of ash. The sum of these, or 2.0736, is the units of ash in the total material lighter than 1.30 specific gravity, which, as shown by column 6, comprises 62.9 percent by weight of the sample. Since $\frac{\text{"weight, percent" x "ash, percent"}}{100} =$ "units of ash", then "units of Ash" x 100 ÷ "weight, percent" = "ash percent", and 2.0736 x 100 ÷ 62.9 = 3.3 percent, the average ash content of the float-on-1.27 fraction combined with the sink-on-1.27 and-float-on-1.30 fraction, or the total float on the liquid of 1.30 specific gravity. The calculations for the third recorded cumulative ash percentage are:

$$\left[\frac{(34.5 \times 2.8)}{100} + \frac{(28.4 \times 3.9)}{100} + \frac{(16.9 \times 8.8)}{100}\right] 100 \div 79.8 = 4.5$$

percent. This system of calculation is continued for all of the specific-grav-fractions down to and including the sink in 1.90.

In constructing washability curves, cross-section paper with centimeter and millimeter divisions is used. This paper should be at least 21 by 25 cm in size. The ordinate and abscissa scales should be in the form shown in Figure 1. An almost indispensable piece of equipment is a No. 48 Copenhagen ship curve.

A. Cumulative Curve

The first curve to be plotted is the one called "cumulative", showing the yield of float coal resulting from a 100-percent efficient separation at any selected cumulative, or average, ash percentage. The curve is outlined in Figure 1 by plotting the percentages found under columns 6 and 7 in Table 1. A smooth curve is drawn through the resulting points.

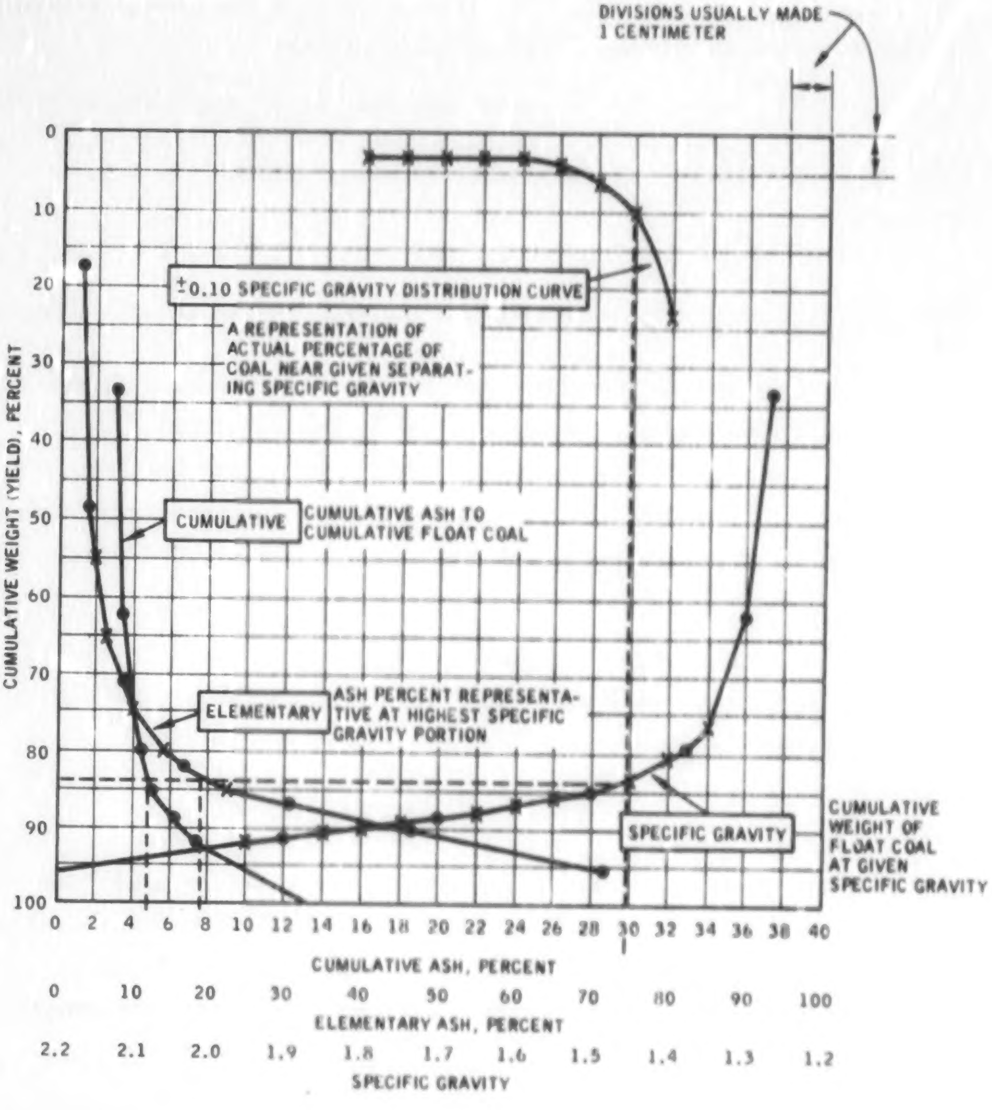
B. Elementary Curve

Mathematically, the elementary curve is a derivation of the cumulative curve and gives an indication of the rate of change of the ash content at different yields. In other words, the elementary curve is intended to indicate the average ash percentage in the highest ash particle group included in a float-coal product, for any given cumulative ash percentage. The elementary curve can be established by the following method.

A rule for calculating points on the elementary curve directly from the float-and-sink data may be expressed as follows:

> One half of the "weight, percent" of the specific-gravity interval involved, plus the "cumulative weight, percent" of all material of lower specific gravity, is plotted against the ash content (not cumulative ash) of the specific gravity interval involved.

(Note that columns 4 and 5 in Table 1 show that 34.5 percent of the total coal is of lower specific gravity than 1.27 and that the



(APPENDIX 3) Figure 1.-Coal-washability curves.

average ash content of this product is 2.8 percent. Obviously, every particle of coal included in this product does not contain exactly 2.8 percent ash. The analysis does not show what the ash range is, but merely that these particles of coal collectively contain 2.8 percent ash.)

Application of the above calculation rule to the values recorded in Table 1 results in the following calculations:

$\frac{34.5}{2}$ or 17.25 percent cumulative weight plotted at 2.8% elementary ash.

$\frac{28.4}{2}$ or 14.2 + 34.5% = 48.7% cumulative weight plotted at 3.9% elementary ash.

= =

$\frac{8.5}{2}$ or 4.25 + 91.5 = 95.75% cumulative weight plotted at 71.3 elem. ash.

Thus three points are shown calculated which serves to illustrate the method of determining points for the elementary curve. The elementary ash curve is an indication of the ease with which coal may be cleaned. Flat slopes mean an easy separation without large changes in the amount of ash removed with small changes in process separating specific gravity.

C. Specific-Gravity Curve

The specific gravity curve in Figure 1 shows the yield of float coal for a perfect separation, meaning laboratory conditions, at any specific gravity within the range of gravities of the float-and-sink tests.

This curve is constructed by plotting the specific gravities listed in column 2 of Table 1 against the corresponding cumulative weight percentage, column 6. In this manner, a series of points plotted from the float-and-sink data are connected to form a smooth curve.

D. The Plus-and-Minus 0.10 Specific Gravity-Distribution Curve

The ± 0.10 specific gravity-distribution curve in Figure 1 shows the percentage by weight of the coal that lies within plus 0.10 and minus 0.10 specific-gravity units at any given specific gravity. For instance, the ± 0.10 value at 1.40 specific gravity is the percentage of the total coal that lies within the 1.30 to 1.50 specific gravity range. At 1.45 specific gravity, the ± 0.10 value is the percentage between 1.35 and 1.55 specific gravity and so on.

The ± 0.10 specific gravity distribution curve is constructed in the following manner: The yield at 1.30 specific gravity is subtracted from the yield at 1.50 specific gravity as read from the specific gravity curve in Figure 1. To compensate for varying amounts of high-gravity materials, especially slate and other rock, the numerical difference in the yields is divided by the yield at 2.00 specific gravity. The resulting adjusted percentage is plotted at 1.40 specific gravity. The reason for dividing the difference in the two yields by the yield at 2.00 specific gravity is that the material of higher specific gravity than 2.00, because of its rapid settling rate, would not interfere with the separation between washed coal and refuse at normal specific gravities. Failure to make this correction would result in the absurd condition where the addition of roof rock to the washery feed would apparently decrease the difficulty of the separation because it would decrease the percentage of material within the ± 0.10 range. The next point is determined by subtracting the yield at 1.35 specific gravity from the yield at 1.55 specific gravity. This difference, divided by the yield at 2.00 specific gravity, is plotted at 1.45 specific gravity. In this manner points are plotted at specific-gravity intervals of 0.05 throughout the range from 1.40 to 1.80 specific gravity.

E. Method of Reading the Washability Curves

Because all of the curves have a common ordinate, values from one of the curves may be expressed in terms of any of the others. This is illustrated by the broken lines in Figure 1 where some additional points not found in Table 1 have been plotted. Assume that the coal to which the curves of Figure 1 apply is of a size range suitable for concentrating-table concentration. A reading of 10 percent on the ± 0.10 specific gravity-distribution curve represents the normal maximum difficulty at which a wet table is capable of effecting an efficient separation. At 10 percent cumulative weight, Figure 1 shows a horizontal broken line that intersects the ± 0.10 curve at 1.452 specific gravity. The vertical broken line at this specific gravity intersects the "Specific Gravity" curve at 83.9 percent cumulative weight, and the horizontal broken line at 83.9 percent cumulative weight is shown to intersect the "Elementary" curve at 19.5 percent ash and the "Cumulative" curve at 5.0 percent ash. In other words, the curves predict that a concentrating table, if expertly operated and if other conditions are favorable, should be capable of washing this coal efficiently to 5.0 percent ash with a theoretical yield of 83.9 percent. Included in the washed coal would be particles containing as high as 19.5 percent ash. The efficiency of the separation is the ratio of the actual yield to the theoretical or float-and-sink yield, and should be about 95 percent. It is not unusual for a table to operate at 97 to 98 percent efficiency, but 95 percent represents the usual average when the object is to produce as clean a washed coal as possible. Thus, the actual yield of 5.0 percent ash washed coal that could be expected is 95 percent of 83.9, or 79.7 percent of the total raw coal feed.

APPENDIX IV

Performance Criteria

Efficiencies as used herein refer to the body of performance criteria which is utilized to evaluate the separation of a feed, as effected by a washing device, into a salable product and a reject.

The quantity and quality of clean coal produced by a cleaning unit are of primary interest to the operator because they determine the economics of the operation. However, both quantity and quality are influenced directly by the density composition of the feed and by the density of the separation. Therefore, the use of yield and ash content to draw direct comparisons between similar cleaning units treating dissimilar feeds or making separations at dissimilar densities is not valid. Nevertheless, yield and ash content are of such vital importance to the operator that to be useful all other criteria should have a direct bearing on them.

Performance criteria used to evaluate cleaning efficiencies are of two principal types: those dependent upon the density composition of the feed, and those substantially independent of the density composition of the feed. A distribution curve is important in performance analysis and will be discussed in connection with independent criteria.

A. Criteria Dependent on Density Composition of Feed

Performance criteria that depend on both the washability characteristics of the coal being treated and the sharpness-of-separation achieved by the washer are called "dependent criteria" and include recovery efficiency, misplaced material, ash error, and yield error.

a) Recovery efficiency is defined as the ratio, expressed as a percentage, of the yield of washed coal to the yield of float coal of the same ash content shown to be present in the feed by the specific-gravity analysis.

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b) Total misplaced material is that percentage of the feed which reports to the wrong product. For sharp separations, the misplaced material is principally composed of that material having specific gravities close to the specific gravity of separation and thus is strongly influenced by the amount of near-gravity material present. Near-gravity material is defined as that percentage of material in the feed ± 0.10 specific-gravity units from the specific gravity of the separation.

c) Ash error is the numerical difference between the actual and theoretical ash contents of washed coal at the yield of washed coal obtained. Ash error takes into account both the amount and quality of improperly treated material, and thus is a direct measurement of impairment in ash content.

d) Yield error is the difference between the yield of coal actually obtained and the theoretical yield at the ash content of the washed coal. Yield error is related arithmetically to efficiency; they simply express the same thing in different terms.

Ash error and yield error are closely related to recovery efficiency and are of special interest inasmuch as they indicate the margin by which actual recovery and ash content of the clean coal product approach the theoretical recovery and ash. Because of the arithmetical relationship between yield error and efficiency, greater yield errors accompany higher yield for any given efficiency.

B. Criteria Independent of Density Composition of Feed

Criteria which are characteristic of the washing unit performance and are substantially unaffected by the density composition of the feed are called "independent criteria" and include probable error, error area, and imprefection. Often referred to as sharpness-of-separation criteria they are obtained from the distribution curve.

a) Distribution curve, the distribution curve plots the percentage of each density fraction of the raw coal that reports to the washed coal against the mean of the density fractions. It can be used to describe the characteristics of actual process equipment. See Figure 1 where a distribution curve has been plotted based on data obtained from a heavy media vessel coal washer.

b) Probable error is obtained directly from the distribution curve. It is numerically equal to one-half the specific-gravity difference between the 25 and 75 percent recovery ordinates on the curve, and thus is an indication of the slope of the distribution curve over a large portion of its range.

c) Error area, the area between the actual distribution curve obtained in practice and a theoretically perfect distribution curve (a theoretically perfect distribution curve indicates 100 percent of the raw coal lighter than the separating gravity going to washed coal and zero percent of the raw coal more dense than the separating gravity going to washed coal), is a measure of the total misplaced material. The total misplaced material includes that material going to clean coal that should have reported to refuse and that material going to refuse that should have reported to clean coal. Error area is a dimensionless number found when the distribution curve is drawn to a uniform scale on which a unit of length that represents 2 percent on the ordinate or weight scale will represent 0.1 specific gravity units on the abscissa or specific gravity scale. The dimensionless number, error area, is the area found as so many square units of the length selected. The error area would be zero for a theoretically perfect separation.

The two criteria, error area and probable error, represent attempts to characterize the total distribution curve with a single value. The convenience of such a procedure is appealing; and, in general, good distribution curves are characterized by low error areas and low probable errors, whereas poor distribution curves are characteriezed by higher values of error area and probable error.

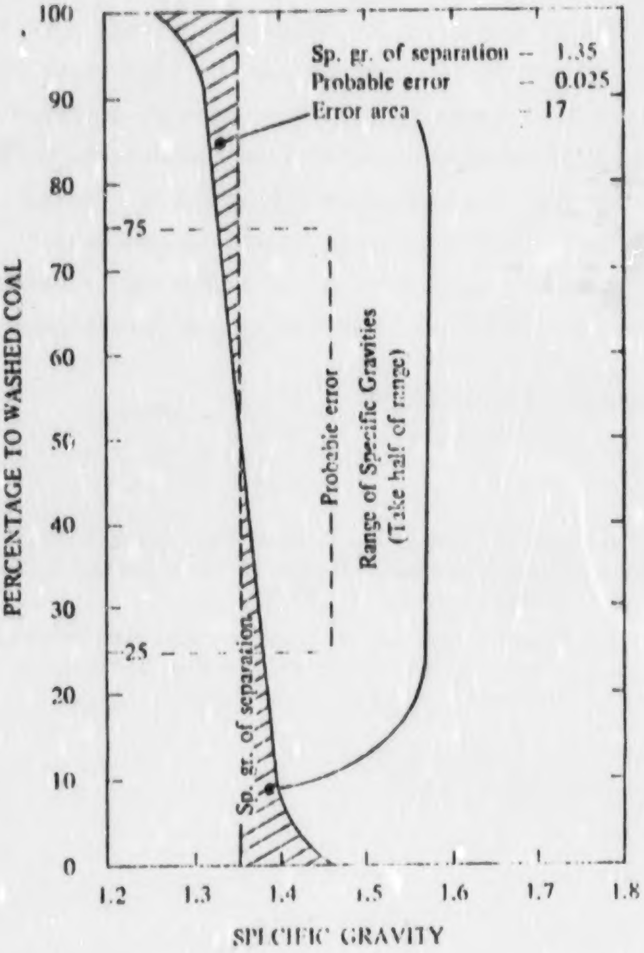
d) The imperfection factor is equal to the probable error divided by the specific gravity of separation (the 50 percent recovery point from the distribution curve) minus the actual specific gravity of the separating medium. For jigs, tables, rheolaveurs and other washers employing water as the separating medium the actual specific gravity of the separating medium is taken to be 1.0 specific gravity. In correcting for the increase in probable error by division using an increasing specific gravity of separation, imperfection provides a unique parameter that characterizes a particular cleaning device regardless of the separating specific gravity and density composition of the feed. However, this value of imperfection is valid only for a given size consist, feed rate, and quality of operation. In symbols:

$$\text{Imperfection Factor} = \frac{d_p}{d_s - d_m} \quad \text{where:}$$

d_p = probable error

d_s = specific gravity of separation from the distribution curve. This is the specific gravity where 50% of that specific gravity in the raw coal reports to clean coal.

d_m = specific gravity of the separating medium used to wash the coal. This specific gravity is taken as 1.0 for jigs etc., higher for heavy media divices.



Distribution Curve for Dense Medium Vessel
Washing 4 inch by 3/8 inch Coal

APPENDIX V

Calculation and Plotting of Distribution Curves

(Adapted from: M.R. Geer and H.F. Yancey, "Chapter 18: Plant Performance and Forecasting Cleaning Results," Coal Preparation, eds. Joseph W. Leonard and David R. Mitchell and Others; sponsored by the Seeley W. Mudd Memorial Fund (Third Edition; New York: The American Institute of Mining, Metallurgical and Petroleum Engineers, 1968).)

An example is perhaps the most satisfactory way to show how the distribution data are calculated and plotted. Table 1 shows the specific gravity analyses of the feed (composite), washed coal and refuse made in the course of a performance test on a baum jig. The analyses of the products are given in the usual way as percentages of the products, and also as percentages of the feed. The latter are obtained, of course, by multiplying the analysis of the product by the yield of that product expressed as a decimal.

Strictly speaking, the distribution data should be plotted against the mean specific gravity of the fraction--the specific gravity at which half of the fraction would float and half would sink. In practice, however, they are plotted against the midpoint of the specific gravity range of the fraction. Assumptions are required in plotting the lightest and heaviest fractions because they have no exact limiting specific gravities. If 1.30 is the lowest specific gravity used in the analysis, as frequently is the case, the point for the float should be plotted at a specific gravity that is midway between that of the lightest particle present and 1.30. A figure of 1.26 to 1.28 generally is used. Any error involved in making this assumption generally has very little influence on the shape and position of the curve; it becomes important only when the specific gravity of separation is unusually low. If 1.80 is the highest specific gravity in the analysis the sink is usually plotted at 2.20 or 2.30, depending on what is known about its composition. If the highest specific gravity is 1.60 the proper position of the point

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(Appendix 5) TABLE 1. - Specific-gravity analyses and distribution data

Specific gravity	Specific gravity analyses, percent of product			Specific gravity analyses, percent of feed [a/]		Disbritution, percent [b/]		
	A Feed	B Washed coal	C Refuse	D Washed coal	E Refuse	F Feed	G Washed coal	H Refuse
Under 1.30	0.2	0.2	0.0	0.2	0.0	100.0	100.0	0.0
1.30 to 1.40	76.1	85.3	9.4	75.0	1.1	100.0	98.6	1.4
1.40 to 1.50	11.2	11.2	11.5	9.8	1.4	100.0	87.5	12.5
1.50 to 1.60	3.6	2.3	13.3	2.0	1.6	100.0	55.6	44.4
1.60 to 1.70	1.8	.6	10.9	.5	1.3	100.0	27.8	72.2
1.70 to 1.80	1.4	.2	9.6	.2	1.2	100.0	14.3	85.7
Over 1.80	5.7	.2	45.3	.2	5.5	100.0	3.5	96.5
Total	100.0	100.0	100.0	87.9	12.1			

a/ Column D obtained by multiplying column B by 87.9 percent, the yield of washed coal; column E obtained in correcponding manner.

b/ Column G obtained by dividing column D by column A. Column H equals 100 minus column G.

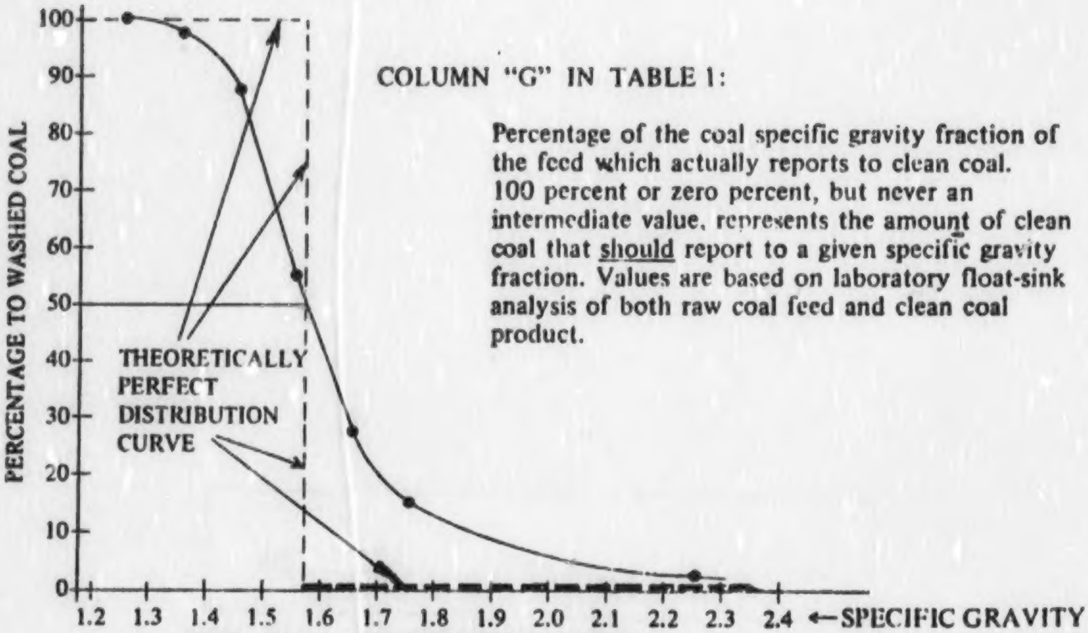
must be lowered accordingly. An error made in selecting the proper specific gravity at which to plot the sink sometimes has a significant influence on the shape of the curve.

Generally the distribution curve is plotted directly against specific gravity. In comparing curves having different specific gravities of separation, however, they may be plotted against the difference between the specific gravity of the fraction and that of the separation.

In Europe it is common practice to plot the distribution curve on either log probability or arithmetic probability paper in an effort to obtain a straight line. The ordinate employed is always percentage recovery on a probability scale, but the specific gravity abcissa scale varies with the type of cleaning unit involved. For dense medium cleaning units the abscissa scale is arithmetic. For processes that employ water it is log d-1 (specific gravity of separation minus one) and for pneumatic processes it is log d.

The advantages inherent in a straight-line plot are appealing. The slope of the line is a measure of the sharpness of the separation and the slope plus the specific gravity of separation combine to characterize the complete curve. In principle, only two points are required to plot the curve; thus a great deal of costly laboratory work would be eliminated. In practice, however, it is found that rarely can a set of distribution data be fitted to a straight line without a loss in accuracy that often is rather large.

See Appendix 4 - Performance Criteria, in the section on Criteria Independent of Density of Composition of Feed where there is additional discussion of distribution data and associated distribution curves.



COLUMN "G" IN TABLE 1:

Percentage of the coal specific gravity fraction of the feed which actually reports to clean coal. 100 percent or zero percent, but never an intermediate value, represents the amount of clean coal that should report to a given specific gravity fraction. Values are based on laboratory float-sink analysis of both raw coal feed and clean coal product.

PLOT DATA: DISTRIBUTION CURVE

APPENDIX VI

Predicting Cleaning Results Using Distribution Curve Data

This appendix is adapted from U.S. Bureau of Mines Information Circular 8093, "Evaluation of Washery Performance," by M.R. Geer and H.F. Yancey which was published in 1962. It should be noted that the prediction of cleaning results applies only to yield and ash of clean coal, and not to the predicted sulfur content.

The projection of anticipated cleaning results--the yield and ash content of the washed coal expected--is a prerequisite step in the design of a new cleaning plant. Such predictions must be made also in connection with the treatment of a new coal in an existing plant, or in evaluating the effect of a proposed change in mining practice that would alter the density composition of the raw coal. Often these predictions are based largely on the judgment of the preparation engineer. Experience in making similar separations in the same type of equipment may provide a figure for recovery efficiency that can be used in conjunction with the density composition of the raw coal to calculate yield and ash content with acceptable accuracy. However, if the separation is particularly difficult, involving an unusually large amount of near-gravity material, or an excessive amount of heavy impurity, the distribution curve recovery-efficiency approach to predicting cleaning results is inadequate.

The distribution curve shows what proportion of each density fraction of the feed will be recovered in the washed coal. It can be used in predicting cleaning results. An example will illustrate the technique employed. Suppose that market considerations indicate that the new coal will require a separation at 1.50 specific gravity. The following tabulation shows the specific-gravity analysis of the new coal and the steps involved in the calculations.

Pages 684 and 685 are blank.

Specific gravity	Specific gravity difference[1]	Distribution factor,[2] percent	Raw coal		Washed Coal[3]
			Weight, percent	Ash, percent	
Under 1.30	−0.22	98.6	20.0	7.0	19.7
1.30 to 1.40	− .15	93.8	52.3	12.3	49.1
1.40 to 1.50	− .05	65.0	11.4	23.8	7.4
1.50 to 1.60	+ .05	33.8	3.8	35.6	1.3
1.60 to 1.70	+ .15	17.4	1.9	41.8	.3
1.70 to 1.80	+ .25	10.3	1.0	50.4	.1
Over 1.80	+ .70	2.6	9.6	77.1	.2
Total	–	–	100.0	–	78.1

[1] Difference between average specific gravity of fraction and specific gravity separation.

[2] Read from distribution curve of figure 2, using upper abscissa scale.

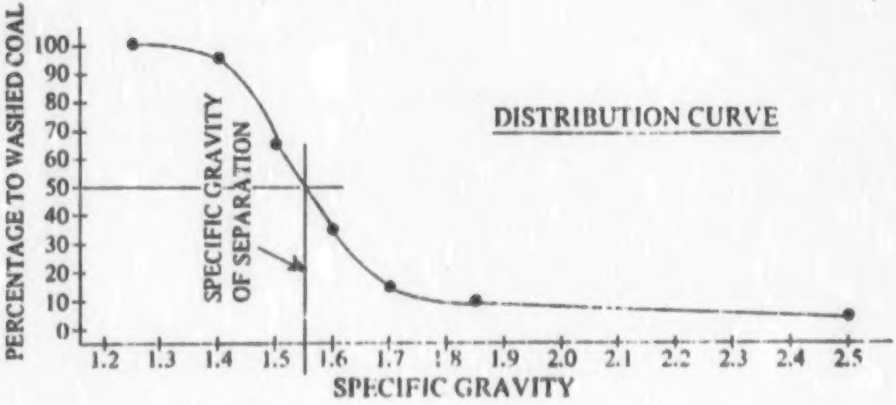
[3] As percentage of raw coal.

The float 1.30 has an assumed average specific gravity 0.22 lower than the specific gravity of separation. Material of this density difference would be distributed 98.6 percent to the washed coal. Therefore, of the 20.0 percent of float 1.30, 19.7 percent (expressed as a percentage of feed) would be recovered in the washed product. Similarly, the next higher density fraction would have an average specific gravity 0.15 lower than the specific gravity of separation, and this would indicate a recovery of this material in the washed coal amounting to 93.8 percent. Thus, of the 52.3 percent of 1.30 to 1.40 in the feed, 49.1 percent would be recovered in the washed product. Similar calculations for each density fraction provide a complete specific gravity analysis of the washed coal expressed in percentage of feed. The sum of these percentages is the anticipated yield of washed coal, in this example 78.1 percent.

The ash content of the washed coal (12.8 percent in this example) is calculated by assuming that each of its density fractions will have the same ash content as the corresponding fraction of the raw coal. Generally this assumption is sufficiently accurate, although the ash content of the heaviest portion of the washed coal ordinarily is substantially lower than the corresponding density fraction in the raw coal. However, the amount of such material generally is so small that its assumed ash content is not significant. For example, in the preceding sample calculation, the ash content of the washed coal is reduced by only 0.1 percent if the ash value assigned to the sink 1.80 fraction is 50.0 instead of 77.1 percent.

A more serious error in calculating ash content may occur when the density of separation falls within a fraction containing a large proportion of the raw coal. If, for example, the separation is at 1.45 specific gravity, the portion of the 1.40 to 1.50 fraction reporting to the washed coal will be somewhat lower in ash content than this fraction of the feed, because it will include primarily the lighter portions of the fraction. Error from this source can be minimized by interpolating on the raw-coal washability curves to subdivide the fraction in which the density of separation occurs into intervals of about 0.02 specific gravity. In this way the gravity range is so small that the difference in ash content between corresponding fractions of the washed coal and raw coal is insignificant.

Obviously, the limitations on use of the distribution curve cited earlier in this report apply when the curve is used in predicting cleaning results. The principal limitation of concern is the necessity of using a curve derived from treating coal having about the same size composition as the one for which the prediction is being made. Although the errors involved in employing a curve having a specific gravity of separation varying from the desired value by 0.20 or more generally are small, ideally a curve representing separation at about the desired density should be used. If these few precautions are observed the prediction of yield and ash content can be suprisingly accurate.


DISTRIBUTION CURVE
PERCENTAGE TO WASHED COAL
100
90
80
70
60
50
40
30
20
10
0
SPECIFIC GRAVITY OF SEPARATION
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
2.3
2.4
2.5
SPECIFIC GRAVITY

APPENDIX VII

List of Applicable ASTM Standards

ASTM D-3174	"Ash in the Analysis of Coal and Coke."
ASTM D-388	"Coals by Rank, Specifications for Classification Of."
ASTM D-2234-68	"Collection of a Gross Sample of Coal."
ASTM D-431-44	"Designating the Size of Coal from its Sieve Analysis."
ASTM D-440	"Drop Shatter Test for Coal."
ASTM D-2492	"Forms of Sulfur in Coal."
ASTM D-720	"Free-Swelling Index of Coal."
ASTM D-409-71	"Grindabiliyt of Coal by the Hardgrove Machine Method."
ASTM D-271-68	"Laboratory Sampling and Analysis of Coal and Coke."
ASTM D-3173	"Moisture in the Analysis of Coal and Coke."
ASTM D-2013-68	"Preparing Coal Samples for Analysis"
ASTM E-323-70	"Perforated-Plate Sieves for Testing Purposes"
ASTM D-3172	"Proximate Analysis of Coal and Coke"
ASTM D-197	"Pulverized Coal, Sampling and Fineness Test"
ASTM D-410-38	"Sieve Analysis of Coal"
ASTM D-311	"Sieve Analysis of Crushed Bituminous Coal"
ASTM D-3302	"Total Moisture in Coal"
ASTM D-3177	"Total Sulfur in the Analysis Sample of Coal and Coke"
ASTM D-3176	"Ultimate Analysis of Coal and Coke"
ASTM D-3175	"Volatile Matter in the Analysis Sample of Coal and Coke."
ASTM E-11-70	"Wire-Cloth Sieves for Testing Purposes."

The latest edition of the entire specification document appears in the ASTM Annual Book of Standards, "Part 26 - Gaseous Fuels; Coal and Coke," or may be obtained as individual publications from:

American Society for Testing and Materials
1916 Race St., Philadelphia, Pa. 19103

Pages 690 and 691 are blank.

APPENDIX VIII

Buying Guide

COAL AGE

1976 Buying Directory

This year's Buying Directory contains a handy reference of up-to-date equipment and services that will help you do your job more efficiently and profitably.

The Buying Directory is divided into two sections:

1. **Product Classification**—An up-to-date alphabetical list of products, materials and services, and the companies that offer them, starting on this page. To help you quickly find the product or service, the listing has been alphabetized both by item and company, and cross-indexed. Note that some product classifications have numbered subdivisions immediately under them. These divisions are designed to help you identify quickly the supplier of a specific type of product. The numbers following the company name thus refer to the numbered items appearing under the product head. For example, if you want to buy corrosion-resistant pipe, look under the general heading **PIPE** and then go through the subdivisions until you find corrosion-resistant, which has the number 8 in front of it. All companies in the alphabetical listing under **PIPE** and having the number 8 after them are suppliers of corrosion-resistant pipe. If a product does not appear under one classification, look for the alternative listing.

2. **Directory of Manufacturers**—Contains in alphabetical order, at the end of this directory, the names and addresses of the manufacturers, suppliers and service organizations appearing in the Product Classification section. Advertisers appear with bullets; see the second to last page of this issue for the page number(s) of the advertisement(s).

ABRASION-RESISTANT MATERIALS

A-S-H Pump, Div. of Envirotech Corp
American Alloy Steel, Inc
Amsco Div., Abex Corp
Asbury Industries, Inc
Badali Co., Inc
Carborundum Company
Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp
Columbia Steel Casting Co., Inc
Corhart Refractories Co., Div. of Corning Glass Works
Detrick, M. H., Co
du Pont de Nemours, E. I. & Co. Inc
Durex Products, Inc., Natl. Wire Cloth Div
ESCO Corp
Fairmont Supply Co
Fiberglass Resources Corp
Galigher Co., The
Gates Rubber Co., The
General Electric Co., Carboloy Systems Dept
Goodrich, B. F., Engineered Systems Co
Greenbank Cast Basalt Eng. Co. Ltd
Greengate Industrial Polymers Ltd
Guyan Machinery Co
Hensley Industries Inc
Holz Rubber Co., A Randron Div
International Alloy Steel Div., Curtis Noll Corp
Jones & Laughlin Steel Corp
Kalenborn
Kanawha Mfg. Co
Lee Supply Co., Inc
Linatex Corp. of America
Lukens Steel Co
3 M Co
Manganese Steel Forge, Taylor Wharton Co., Div. of Harsco Corp
Molded Dimensions Inc
Norton Co
Oil Center Research
Poly-Hi, Inc
Preiser/Mineco Div., Preiser Scientific Inc
Ryerson, Joseph T., & Son, Inc
Shwayder Co
Smith, A. O.-Inland Inc. Reinforced Plastics Div
Steel Heddle Mfg. Co., Industrial Div
Stellite Div., Cabot Corp
Stonhard, Inc
Stoody Co
Stoody Co., WRAP Div
Thomas Foundries Inc
Trelleborg Rubber Co., Inc
Tricon Metals & Services, Inc
Trowelon, Inc
U. S. Polymeric, Sub. of Armco Steel Corp
United States Steel Corp
Wajax Industries Ltd
Wall Colmonoy
West Virginia Belt Sales & Repairs Inc
Wilmot Engineering Co
Workman Developments, Inc

AERIAL SURVEYING, MAPPING, PHOTOGRAPHY

Aerial Map Service Co
Aerial Surveys, Inc
Aero Service Div., Western Geophysical Co. of Amer
Berger Associates, Ltd
Geometrics
Griffolyn Co., Inc
Numonics Corp
Westinghouse Electric Corp
Wild Heerbrugg Insts. Inc

AERIAL TRAMWAYS

Interstate Equipment Corp
United States Steel Corp

ANALYZERS, COAL SULFUR

Beckman Instruments, Inc
KHD Industrieanlagen AG, Humboldt Wedag
Leco Corp
Perkin Elmer Corp
Preiser/Mineco Div., Preiser Scientific Inc

ANALYZERS, GASES, VAPORS, ATMOSPHERE

A T O Inc
Bacharach Instrument Co., Mining Div
Barnes Engineering Co
Beckman Instruments, Inc
Bullard, E. D. Co
du Pont de Nemours, E. I. & Co. Inc
Edmont-Wilson, Div. of Becton, Dickinson & Co
Fisher Scientific Co
Leeds & Northrup Co
Mine Safety Appliances Co
National Environmental Inst. Inc
National Mine Service Co
Perkin-Elmer Corp
Preiser/Mineco Div., Preiser Scientific Inc
Scott Aviation, A Div. of A-T-O, Inc
Taylor Instrument Process Control Div., Sybron Corp
Varian Associates

ANEMOMETERS

Alnor Instrument Co
Bacharach Instrument Co., Mining Div
CSE Mine Service Co
Davis Instrument Mfg. Co
Fisher Scientific Co
J-Tec Associates, Inc
Mine Safety Appliances Co
National Mine Service Co
Preiser/Mineco Div., Preiser Scientific Inc

BAGS

1 AIR FILTERS, DUST COLLECTORS
2 AN-FO, NCN
3 EXPLOSIVES
4 TAMPING
5 SAMPLE

Aeroiall Mills Ltd., (1)
American Air Filter Co., Inc., (1)
Atlas Powder Co., (4)
Austin Powder Co., (2, 3, 4)
Bemis Co., Inc., (1, 2, 3, 4, 5)
Daniels, C. R., Inc
du Pont de Nemours, E. I. & Co. Inc., (4)
Energy Packaging, Inc., (2, 3)
Fairmont Supply Co., (4)
Firestone Tire & Rubber Co., (1)
Hercules Inc., (2, 3, 4)
Independent Explosives Co., (2, 3, 4)
Joy Mfg. Co. (U.K.) Ltd., (1)
KHD Industrieanlagen AG, Humboldt Wedag, (1)
Logan Corp., (4)
Monsanto Co., (2, 3, 4)
National Filter Media Corp., (1)
National Mine Service Co., (4)
Peabody ABC, (1, 3, 5)
Preiser/Mineco Div., Preiser Scientific Inc., (5)
Sly, W. W., Mfg. Co., (1)
Smico Corp., (1)
Sprout Waldron, Koppers Co., Inc., (1)
Trojan Div. IMC Chemical Group, Inc., (2, 3, 4)
West Virginia Belt Sales & Repairs Inc., (4)
Western Precipitation Div., Joy Mfg. Co., (1)
Wheelabrator Frye Inc., Air Pollution Control Div., (1)
Wilson, R. M., Co., (1)
Wire Cloth Enterprises, Inc., (1)

BARGE-HANDLING EQUIPMENT

Easton Car & Construction Co
FMC Corp., Link Belt Material Handling Systems Div
Heyl & Patterson, Inc
Kanawha Mfg. Co
McDowell Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Webster Mfg. Co

BARGE LINES

ALPS Wire Rope Corp
American Commercial Barge Line Co
Armco Steel Corp., Product Info
Dravo Corp
Flowers Transportation, Inc
M/G Transport Services, Inc
Midland Enterprises Inc
Ohio River Co., The

BARGES

American Commercial Barge Line Co
Bethlehem Steel Corp
Dravo Corp
Marathon Mfg. Co
United States Steel Corp

BASKETS, CLOTHES

Anixter Mine & Smelter Supply
Fairmont Supply Co
Lyon Metal Prods. Inc
Moore Co., The
National Mine Service Co

BELT-LOADING STATIONS, AUTOMATIC

Aggregates Equipment Inc
DEMAG Lauchhammer
Dowty Corp
FMC Corp., Link-Belt Material Handling Systems Div
Fairfield Engineering Co
Hanson, R.A., Disc., Ltd
Huwood-Irwin Co
Joid Mfg. Co., Inc
McDowell Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Mintec/International, Div. of Barber Greene
Rexnord Inc
Schroeder Bros. Corp
Stamler, W. R., Corp., The
Webb, Jervis B., Co
Webster Mfg. Co
Wilson, R. M., Co

BELTS

1 CHAIN
2 FLAT TRANSMISSION
3 MINER'S LEATHER
4 V BELT
5 V LINK

Acme-Hamilton Mfg. Corp., Belting Div., (2)
Adams Equipment Co., Inc., (4)
Baldwin Belting Inc., (2, 3, 4)
Banner Bearings, (4)
Big Sandy Electric & Supply Co., Inc., (4)
Bonded Scale & Machine Co., (1)
Boston Industrial Products Div., American Biltrite Inc., (2, 4)
Bowman Distribution, Barnes Group Inc., (2, 4)
Bridgestone Tire Co., Ltd., (2, 4)
Browning Mfg. Div., Emerson Electric Co., (4, 5)
CE Tyler Inc
Campbell Chain Co., (1)
Celanese Fibers Marketing Co., (5)
Cincinnati Rubber Mfg. Co., Div. of Stewart Warner Corp., (2)
Dayco Corp., Rubber Products Div., (2, 4, 5)
Dick Inc., R. J., (2, 4, 5)
Dodge Div., Reliance Electric Co., (4, 5)
Duplex Mill & Mfg. Co., (4)
Eaton Corp., World Headquarters, (4, 5)
Eaton Corp., Industrial Drives Div., (4)
FMC Corp., Chain Div., (1)
Fairmont Supply Co., (1, 2, 4, 5)
Fenner, J. H. & Co. Ltd., (1, 4, 5)
Firestone Tire & Rubber Co., (4)
Flexible Steel Lacing Co., (4)
Gates Rubber Co., The, (4)
Goodall Rubber Co., (2, 4)
Goodrich, B. F., Engineered Systems Co., (2)
Goodyear Tire & Rubber Co., (2, 4)
Greengate Industrial Polymers Ltd., (2, 4)
Holz Rubber Co., A Randron Div., (2)
Huwood Irwin Co
Industrial Rubber Products Co., (1, 2, 4, 5)
Lee Supply Co., Inc
Logan Corp., (4)
Manheim Mfg. & Belting, (2, 4, 5)
Mine Safety Appliances Co., (3)
National Mine Service Co., (3)
Rexnord Inc., (1)
Rost, H. & Co., (2)
Rubber Engineering & Mfg. Co., (2)
Scandura, Inc., (2)
Shingle, L. H., Co., (2, 4)
Trelleborg Rubber Co., Inc., (4)
Unilok Belting Co., Div. of Georgia Duck and Cordage Mill, (2)
Uniroyal, Inc., (2, 4)
Webster Mfg. Co., (1)
Wilson, R. M., Co., (4)
Wood's, T. B., Sons Co., (4, 5)

BIN GATES

Aggregates Equipment Inc
Bonded Scale & Machine Co
Card Corp
Challenge-Cook Bros., Inc
Cleveland Armstrong Corp
Concrete Equipment Co., Inc
Dorr Oliver Long Ltd
FMC Corp., Link-Belt Material Handling Systems Div
Fairfield Engineering Co
Feeco International, Inc
Fuller Co., A Gatx Co
Industrial Contracting of Fairmont, Inc
Industrial Pneumatic Systems, Sub of Industrial Contracting of Fairmont, Inc
Industrial Rubber Products Co
Kanawha Mfg. Co
Leman Machine Co
Lively Mfg. & Equipment Co
Marsh, E. F., Engineering Co
McNally Pittsburg Mfg. Corp
Somerset Welding & Steel Inc
Standard Metal Mfg. Co
Stephens Adamson
Telsmith Div., Barber Greene Co
Universal Road Machinery Co
Webster Mfg. Co
Wilks & Paul Corp., The

BIN-LEVEL INDICATORS

Automation Products, Inc
Big Noise Instruments, Div. of Improvecon Corp
Bindicator Co., Div. of Improvecon Corp
Compton Electrical Equipment Corp
Concrete Equipment Co., Inc
Delavan Electronics, Inc
FMC Corp., Material Handling Equipment Div
Fairfield Engineering Co
Ferro Tech, Inc
Fuller Co., A Gatx Co
Huwood Irwin Co
Industrial Rubber Products Co
Jeffrey Mfg. Div., Dresser Industries Inc
Kay Ray Inc
McNally Pittsburg Mfg. Corp
Metritape Inc
Micro Switch, A Div. of Honeywell
Mineral Services Inc
Monitor Mfg. Co
Montrol Mfg. Co
Ohmart Corp
Ramsey Engineering Co
Stephens Adamson
Stevens, Inc., C. W
Texas Nuclear
Unique Products Co
WESMAR Level Monitor Div

BIN VIBRATORS

1 AIR OR GAS

Branford Vibrator Co., The, Div. of Electro Mechanics, Inc
Carman Industries, Inc
Eriez Magnetics
FMC Corp., Material Handling Equipment Div
Firestone Tire & Rubber Co
Industrial Rubber Products Co
Long-Airdox Co. A Div. of the Marmon Group, Inc., (1)
Preiser/Mineco Div., Preiser Scientific Inc
Thayer Scale Hyer Industries, (1)
Vibco Inc., (1)
Vibranetics, Inc
Wilson, R. M., Co., (1)

BINS

1 CONCRETE-COAL STORAGE
2 BLENDING
3 REFUSE
4 PARTS STORAGE

ASV Engineering Ltd., (1, 2, 3, 4)
Armco Steel Corp., Product Info
Asbury Industries, Inc., (3, 4)
Bethlehem Steel Corp., (1)
Bowman Distribution, Barnes Group, Inc., (4)
Concrete Equipment Co., Inc
Fabricated Metals Industries, Inc
Fairmont Supply Co., (4)
Feeco International, Inc., (1, 2, 3)
Ferro-Tech, Inc
First Colony Corp., (1)
Frick-Gallagher Mfg. Co., The, (4)
Hammermills, Inc., Sub. of Pettibone Corp., (2)
Holmes Bros. Inc
I & M Equipment Sales, Inc
Industrial Contracting of Fairmont, Inc., (1, 3)
Industrial Pneumatic Systems, Sub of Industrial Contracting of Fairmont, Inc., (1)
Iowa Manufacturing Co., (1)
Kanawha Mfg. Co., (2, 3)
Lively Mfg. & Equipment Co., (1, 2, 3)
Lyon Metal Prods. Inc., (4)
MacDonald Engineering Co., (1, 2)
Manufacturers Equipment Co., The
Marietta Concrete Co., (1, 2, 3)
Marsh, E. F., Engineering Co., (2)
McNally Pittsburg Mfg. Corp., (1, 2, 3)
Neff & Fry, Inc., (1)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 2, 3, 4)
Republic Steel Corp., (4)
Ripco, Inc
Ruttmann Companies, (1, 2, 3)
St. Regis Paper Co., (3, 4)
Sprout-Waldron, Koppers Co., Inc
Standard Metal Mfg. Co., (1)
Vibra Screw Inc., (2)
Wilks & Paul Corp., The, (1, 2, 3)
Wilson, R. M., Co., (1, 3, 4)

BLENDERS-COAL

FMC Corp., Link-Belt Material Handling Systems Div
Feeco International, Inc
Gundlach, T. J., Machine Co., Div. J. M. J. Industries, Inc
Heyl & Patterson, Inc
Jenkins of Retford Ltd
K-G Industries, Inc
McDowell-Wellman Engrg. Co
McLanahan Corp
Patterson-Kelley Co., Div. of Taylor Wharton Co., Harsco Corp
Preiser/Mineco Div., Preiser Scientific Inc
Wilson, R. M., Co

BLENDING & PROPORTIONING SYSTEMS-COAL

ASV Engineering Ltd
Duplex Mill & Mfg. Co
FMC Corp., Link-Belt Material Handling Systems Div
FMC Corp., Material Handling Equipment Div
Fairfield Engineering Co
Feeco International, Inc
GEC Mechanical Handling Ltd
Hawker Siddeley Dynamics Engineering Ltd
Heyl & Patterson, Inc
Jenkins of Retford Ltd
K-G Industries, Inc
Kaiser Engineers, Inc
Kanawha Mfg. Co
K-Tron Corp
Lively Mfg. & Equipment Co
Marsh, E. F., Engineering Co
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Mintec/International, Div. of Barber Greene
Patterson-Kelley Co., Div. of Taylor Wharton Co., Harsco Corp
Ramsey Engineering Co
Thayer Scale Hyer Industries

BOX-CAR LOADERS, UNLOADERS

Branford Vibrator Co., The, Div. of Electro Mechanics, Inc
Industrial Rubber Products Co
Mining Equipment Mfg. Corp
NEI International Ltd
Schroeder Bros. Corp

BREAKERS

1 COAL ROTARY
2 LUMP, MINE
3 PICK TYPE, PREPARATION

British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch), (1, 2, 3)
Card Corp., (1)
Daniels Company, The, (1)
Emaco Inc
Ferro Tech, Inc., (1, 2)
GEC Mechanical Handling Ltd., (1)
Gruendler Crusher & Pulverizer Co., (1)
Gundlach, T. J., Machine Co., Div. J. M. J. Industries, Inc
Hemscheidt America, (2)
Heyl & Patterson, Inc., (1)
Jenkins of Retford Ltd., (3)
Joy Mfg. Co. (U.K.) Ltd., (3)
K-G Industries, Inc
Koppers Co., Inc., (1)
Koppers Co., Inc., Metal Products Div., Hardinge Operation, (1)
Lively Mfg. & Equipment Co., (1)
Long-Airdox Co. A Div. of the Marmon Group, Inc., (1, 2)
McLanahan Corp., (1, 2)
McNally Pittsburg Mfg. Corp., (1)
Mining Progress, Inc., (1, 2)
Mining Supplies, Ltd., (2)
Owens Mfg., Inc., (1, 2, 3)
Pennsylvania Crusher Corp., (1, 2)
Schroeder Bros. Corp., (1)
Stamler, W. R., Corp., The, (1, 2)
Sturtevant Mill Co., (1)
Wilson, R. M., Co., (1, 2)

BUCKETS

1 AERIAL TRAMWAY
2 CLAMSHELL
3 DRAGLINE
4 DRAGLINE ARCHES, CHAINS
5 ELEVATOR
6 TRACTOR AND WHEEL LOADER

Aggregates Equipment Inc., (5)
Allis-Chalmers, (6)
American Poclain Corp., (2)
Asbury Industries, Inc., (5, 6)
Balderson Inc., (6)
Bucyrus-Erie Co., (4)
Budd Co., Plastic Products Div., Polychem Products, (5)
Card Corp
Caterpillar Tractor Co., (6)
Concrete Equipment Co., Inc., (5)
Duplex Mill & Mfg. Co., (5)
Elkhorn Industrial Products Corp., (6)
ESCO Corp., (2, 3, 4, 5)
FMC Corp., Material Handling Equipment Div., (5)
Fairfield Engineering Co., (5)
Fairmont Supply Co., (5)
Ferro Tech, Inc
Fiat-Allis Construction Machinery, Inc., (6)
Haulmasters, Inc., (3)
Hendrix Mfg. Co., Inc., (3)
Industrial Rubber Products Co., (5)
Interstate Equipment Corp., (1)
Jeffrey Mfg. Div., Dresser Industries Inc., (5)
KHD Industrieanlagen AG, Humboldt Wedag
Kanawha Mfg. Co., (5)
Laubenstein Mfg. Co., (5)
Marion Power Shovel Co. Inc., (3, 4)
McNally Pittsburg Mfg. Corp., (5)
Ore Reclamation Co., (5)
Owen Bucket Co., The, (2)
Page Engrg. Co., (3)
Pettibone Corp., (2, 3)
Philippi-Hagenbuch Inc. Ltd., (6)
Rexnord Inc., (5)
S & S Machinery Sales, Inc., (6)
Standard Metal Mfg. Co., (5)
Stephens Adamson, (5)
Terex Div., GMC, (6)
Uni Tool Attachments, Inc., (6)
Webster Mfg. Co., (5)
Wilmot Engineering Co., (5)
Wilson, R. M., Co., (1, 5)
Workman Developments, Inc., (1, 5)
Yaun Williams Bucket Co., (2, 3, 4)
Young Corp., (6)

CAR DUMPERS, MINE

Atlas Railroad Construction Co
Card Corp
Connellsville Corp
Dorr Oliver Long Ltd
FMC Corp., Link-Belt Material Handling Systems Div
Heyl & Patterson, Inc
Kanawha Mfg. Co
McNally Pittsburg Mfg. Corp
Mining Equipment Mfg. Corp
Nolan Co., The
Roberts & Schaefer Co

CAR DUMPERS, R.R. ROTARY

Aggregates Equipment Inc
Atlas Railroad Construction Co
Dilco, Inc
Dorr Oliver Long, Ltd
FMC Corp., Link-Belt Material Handling Systems Div
Heyl & Patterson, Inc
McDowell-Wellman Engrg. Co
Mining Equipment Mfg. Corp
National Air Vibrator Co
Whiting Corp

CAR HAULS, MOVERS, PULLERS, R.R.

Aldon Company, The
Atlantic Track & Turnout Co
CE Ehrsam
Coeur d'Alenes Co
Dorr Oliver Long, Ltd
FMC Corp., Link-Belt Material Handling Systems Div
Fairmont Supply Co
Heyl & Patterson, Inc
ISCO Mfg. Co
Marmon Transmotive Div., Sanford Day Products
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Nolan Co., The
Pettibone Corp., Pettibone New York Div
Roberts & Schaefer Co
Stamler, W. R. Corp., The
Stephens-Adamson
Whiting Corp

CAR HOLDERS, STOPS, MINE

Abex Corp., Railroad Products Group
Aldon Company, The
Card Corp
Connellsville Corp.
Dorr Oliver Long, Ltd
Duquesne Mine Supply Co
Huwood-Irwin Co
Kanawha Mfg. Co
Marmon Transmotive Div., Sanford Day Products
Midwest Steel Div., Midwest Corp
Nolan Co., The

CAR-LOADING STATIONS, AUTOMATIC-MINE-CAR

Card Corp
Dorr Oliver Long, Ltd
Kaiser Engineers, Inc
Marmon Transmotive Div., Sanford Day Products
Nolan Co., The
Schroeder Bros. Corp
Stamler, W. R. Corp., The
Wilson, R. M. Co

CAR-LOADING STATIONS, AUTOMATIC-R.R.-CAR

Dorr Oliver Long, Ltd
FMC Corp., Link-Belt Material Handling Systems Div
Fairfield Engineering Co
General Electric Co., Transportation Systems Business Div
Heyl & Patterson, Inc
Kaiser Engineers, Inc
Marmon Transmotive Div., Sanford Day Products
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Minlec/International, Div. of Barber-Greene
Nolan Co., The
Schroeder Bros. Corp
Stamler, W. R., Corp., The
Webster Mfg. Co
Whiting Corp

CAR MOVERS, R.R.

A & K Railroad Materials, Inc
Advance Car Mover Co., Inc
Aldon Company, The
Anixter Mine & Smelter Supply
Atlantic Track & Turnout Co
Clark Equipment Co., Construction Machinery Div
Coeur d'Alenes Co
Dorr Oliver Long, Ltd
Fairmont Supply Co
General Scientific Equipment Co
ISCO Mfg. Co
Marmon Transmotive Div., Sanford Day Products
McDowell-Wellman Engrg. Co
Midwest Steel Div., Midwest Corp
Nolan Co., The
Pettibone Corp., Pettibone New York Div
Sanford Day/Marmon Transmotive, Div. of the Marmon Group, Inc
Stamler, W. R., Corp., The
Stephens-Adamson
Wajax Industries Ltd
Whiting Corp

CAR RETARDERS, MINE-CAR

Abex Corp., Railroad Products Group
Aldon Company, The
Dorr Oliver Long, Ltd
Duquesne Mine Supply Co
FMC Corp., Link-Belt Material Handling Systems Div
Fairmont Supply Co
Jenkins of Retford Ltd
Kanawha Mfg. Co
Marmon Transmotive Div., Sanford Day Products
Sanford-Day/Marmon Transmotive, Div. of the Marmon Group, Inc

CAR RETARDERS, R.R. CAR

Abex Corp., Railroad Products Group
Aldon Company, The
Atlas Railroad Construction Co
Duquesne Mine Supply Co
FMC Corp., Link-Belt Material Handling Systems Div
Heyl & Patterson, Inc
Kanawha Mfg. Co
Logan Corp.
Marmon Transmotive Div., Sanford Day Products
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
WABCO Union Switch & Signal Div., Westinghouse Air Brake Co., an American Standard Co.

CAR SHAKERS, R.R.

Aldon Company, The
Allis Chalmers
Allis-Chalmers, Crushing & Screening Equipment
Branford Vibrator Co., The, Div. of Electro Mechanics, Inc
Industrial Rubber Products Co
Logan Corp
National Air Vibrator Co
Vibco Inc

CAR SPOTTERS, MOVERS, MINE

Aldon Company, The
FMC Corp., Material Handling Equipment Div
ISCO Mfg. Co
Kanawha Mfg. Co
Marmon Transmotive Div., Sanford Day Products
Morgantown Machine & Hydraulics, Inc., Div. Natl. Mine Service Co
Nolan Co., The
Schroeder Bros. Corp
Stamler, W. R., Corp., The

CHUTES

1 DIVERSION, COAL LOADING
2 TELESCOPING, COAL LOADING

ASV Engineering Ltd., (1)
Bethlehem Steel Corp., (1)
Cleveland-Armstrong Corp., (1)
Concrete Equipment Co., Inc
FMC Corp., Link-Belt Material Handling Systems Div., (1, 2)
Fairfield Engineering Co
Holmes Bros. Inc., (2)
Industrial Contracting of Fairmont, Inc., (1)
Kanawha Mfg. Co., (1, 2)
Laubenstein Mfg. Co
Lively Mfg. & Equipment Co., (1, 2)
McNally Pittsburg Mfg. Corp., (1, 2)
Savage, W. J. Co., (1)
Somerset Welding & Steel Inc., (1)
Stamler, W. R., Corp., The, (1)
Trelleborg Rubber Co., Inc., (1, 2)
United McGill Corp
Webb, Jervis B., Co., (1, 2)
Webster Mfg. Co., (1, 2)
Wilkins & Paul Corp., The
Wilson, R. M., Co., (1, 2)
Workman Developments, Inc

CLARIFIERS

Crane Co.
Dorr-Oliver Inc
Dorr Oliver Long, Ltd
Envirex, Inc.
Enviro-Clear, a Div. of Amstar Corp.
Environmental Equip. Div., FMC Corp
Envirotech Corp., Eimco BSP Div
Heyl & Patterson, Inc.
Joy Mfg. Co., Denver Equipment Div.
KHD Industrieanlagen AG, Humboldt Wedag
Koppers Co., Inc.
Parkson Corp.
Redding Co., James A.
Rexnord Inc.
Sala International
Unifloc Limited

CLASSIFIERS

1 AIR
2 HYDRAULIC
3 MECHANICAL

Aerofall Mills Ltd., (1)
C-E Raymond/Bartlett-Snow, Div. Combustion Engineering, Inc., (1, 3)
CE Tyler Inc., (3)
Daniels Company, The, (3)
Deister Concentrator Co. Inc., The, (2)
Dorr-Oliver Inc., (2)
Dorr Oliver Long, Ltd., (2, 3)
General Resource Corp
Gruendler Crusher & Pulverizer Co., (1)
Heyl & Patterson, Inc., (2)
Joy Mfg. Co., Denver Equipment Div.
KHD Industrieanlagen AG, Humboldt Wedag, (1, 3)

Kennedy Van Saun Corp. Sub. of McNally Pittsburg, (1)
Krebs Engineers, (2)
Linatex Corp. of America, (2)
Majac Div., Donaldson Co., (1)
McLanahan Corp., (2)
McNally Pittsburg Mfg. Corp., (3)
Rexnord Inc., (3)
Sala International, (1, 2, 3)
Sturtevant Mill Co., (1, 3)
Telsmith Div., Barber-Greene Co., (3)
Unifloc Limited
Universal Road Machinery Co., (1)
WEMCO Div., Envirotech Corp., (2)
Williams Patent Crusher & Pulv. Co., (1)
Wilmot Engineering Co., (3)
Wilson, R. M., Co., (3)

CLEANERS, AIR, FOR COAL

(SEE TABLES, AIR)

COAL-ANALYSIS LABORATORIES

Commercial Testing & Engineering Co.
Fisher Scientific Co.
Hazen Research, Inc.
Preiser/Mineco Div., Preiser Scientific Inc.
Unifloc Limited

COAL BREAKERS, CO2, AIR

Eagle Crusher Co., Inc.
Long-Airdox Co. A Div. of the Marmon Group, Inc.

COAL INSPECTION, SAMPLING

Commercial Testing & Engineering Co.
Holmes Bros. Inc.
Kaiser Engineers, Inc.
Mathews, Abe W., Engineering Co.
McNally Pittsburg Mfg. Corp.
Weir, Paul Co., Inc.

COAL STORAGE

(SEE STORAGE & RECLAIMING SYSTEMS)

COMMUNICATORS, INTEROFFICE & PLANT

CSE Mine Service Co.
Collins Radio
Communication & Control Eng. Co. Ltd.
Davis, John & Son (Derby) Ltd.
Femco Div., Gulton Industries, Inc.
Gai-Tronics Corp.
Jabco, Inc.
3 M Co.
Mine Safety Appliances Co.
Motorola Communications & Electronics
Schroeder Bros. Corp.
Stromberg-Carlson Corp.
Wilson, R. M., Co

CONTROLS

1 CABLE-TYPE
2 INDUCTIVE-CARRIER REMOTE
3 LIQUID-LEVEL
4 SOLIDS-LEVEL
5 STATIC
6 REMOTE, AUTOMATIC, R R
7 CONVEYOR

Acco, Bristol Div., (3)
Acco, Cable Controls Div., (1)
Acco, Integrated Handling Systems Div., (7)
Allen Bradley Co., (3)
Allis-Chalmers, (5)
Alnor Instrument Co
Automation Products, Inc., (3, 4)
Babcock & Wilcox, (3)
Big Horse Instruments, Div. of Improvecon Corp., (4)
Bindicator Co., Div. of Improvecon Corp., (3, 4)
Collins Radio, (6)
Communication & Control Eng Co Ltd., (3, 5, 7)
Compton Electrical Equipment Corp., (1, 3, 4, 7)
Continental Conveyor & Equipment Co., (7)
Control Products, Inc., (1, 7)
Controlled Systems Inc., (5, 7)
Conveyor Components Co., (1, 7)
Crouse-Hinds Co., (7)
Cutler-Hammer, Inc., (4, 5, 6, 7)
Delavan Electronics, Inc., (3, 4)
Diversified Electronics, Inc.
Eaton Corp., Industrial Drives Div., (7)
Eaton Corp., Transmission Div.
Electric Machinery Mfg. Co., (3)
FMC Corp., Material Handling Equipment Div., (4)
Fairfield Engineering Co., (6, 7)
Femco Div., Gulton Industries, Inc., (2, 6)
Fisher Controls Co., (3, 4)
Foxboro Co., The, (3)
Fuller Co., A Gatx Co., (4)
GTE Sylvania Inc., (5, 7)
General Electric Co., Industrial Sales Div., (3, 5, 7)
General Electric Co., Transportation Systems Business Div., (6)
General Equipment & Mfg. Co., Inc., (6, 7)
General Resource Corp., (7)
Grindex-CWI Distributing Co., (3)
Hawker Siddeley Dynamics Engineering Ltd (6, 7)
Honeywell Inc., Process Control Div., (3)
Huwood-Irwin Co., (7)
Huwood Limited, (6, 7)
Jabco, Inc., (6, 7)
Jeffrey Mining Machinery Div., Dresser Industries Inc. (7)
Joy Mfg. Co., Denver Equipment Div., (3)
Kay-Ray Inc., (3, 4)
Leeds & Northrup Co., (3)
Louis Allis Div., Litton Industrial Products, Inc., (5)
Metritape Inc., (3, 4)
Micro Switch, A Div. of Honeywell, (3, 4, 7)
Mineral Services Inc.
Monitor Mfg. Co., (4)
Morse Controls Div., Rockwell Intl
Motorola Communications & Electronics, (6)
National Electric Coil Div. of McGraw Edison Co., (3, 6)
Ohmart Corp., (3, 4)
Pace Transducer Co., Div. of C J Enterprises, (3)
Phelps Dodge Industries, Inc., (1)
Preiser/Mineco Div., Preiser Scientific Inc., (3, 4, 7)
Reliance Electric Co., (5)
Revere Corp. of America, Sub. of Neptune Intl. Corp., (3)
Robicon Corp., (5)
Square D Co., (3)
Stevens, Inc., C W
Taylor Instrument Process Control Div. Sybron Corp., (3)
Texas Nuclear (3, 4)
Unique Products Co., (3, 4, 7)
WABCO Union Switch & Signal Div., Westinghouse Air Brake Co., an American Standard Co., (6)
Weatherhead Co., The, (1)
Webb, Jervis B., Co., (7)
WESMAR Level Monitor Div., (3, 4)
West Virginia Armature Co. (7)
Westinghouse Electric Corp., (3, 5, 6)
Wichita Clutch Co., Inc.

CONVEYING SYSTEMS

1. HYDRAULIC
2. PNEUMATIC

Cable Belt Conveyors Inc
D P Way Corp., (2)
Ducon Co., Inc., The, (2)
ESCO Corp., (2)
Ferro-Tech, Inc., (2)
Fuller Co., A Gatx Co., (2)
GEC Mechanical Handling Ltd., (2)
General Resource Corp., (2)
Hammermills, Inc., Sub. of Pettibone Corp., (1, 2)
Hanson, R A, Disc., Ltd
Industrial Contracting of Fairmont, Inc., (2)
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc., (2)
Industrial Rubber Products Co
KHD Industrieanlagen AG, Humboldt Wedag, (1, 2)
Kennedy Van Saun Corp. Sub. of McNally Pittsburg, (2)
Lake Shore, Inc.
Logan Corp
Long-Airdox Co. A Div. of the Marmon Group, Inc., (1, 2)
Macawber Engineering Ltd., (2)
Manufacturers Equipment Co., The, (2)
Mining Equipment Mfg. Corp., (1, 2)
NFE International Ltd., (2)
Reed Manufacturing, (2)
Rexnord Inc
Ripco, Inc. (2)
Sprout-Waldron, Koppers Co., Inc., (2)
Treadwell Corp., (1, 2)
West Virginia Armature Co., (1)

CONVEYOR-BELT PARTS, SERVICES

1 CLAMPS
2 CLEANERS
3 CLEATS
4. COLD VULCANIZING
5 CUTTERS
6 DRIVE PULLEYS
7 FASTENERS, SPLICING MATERIALS
8 IDLER PULLEYS
9 LOADING STATIONS, MINE, AUTOMATIC
10 REPAIR KITS
11 REPAIR MATERIAL
12 REPAIR SERVICE
13 SPLICING, SHOP & FIELD
14 TIGHTENERS
15 TRIPPERS
16 VULCANIZERS
17 WINDERS
18 CONTROL SWITCHES

Aggregates Equipment Inc., (7, 8)
Anderson Mavor (USA) Ltd. (8)
Armstrong, Bray & Co., (7)
Automatic Vulcanizers Corp., (3, 4, 7, 10, 11, 12, 13, 16)
Baldwin Belting Inc., (2, 4, 6, 7, 8, 12, 13, 14)
Banner Bearings, (6, 8)
Barber-Greene Co., (2, 6, 8, 15)
Bekaert Steel Wire Corp
Big Sandy Electric & Supply Co., Inc., (6, 7)
Bonded Scale & Machine Co. (2, 6, 7, 8)
Browning Mfg. Div., Emerson Electric Co., (6, 8)
CE Ehrsam, (8, 15)
CSE Mine Service Co., (7, 8, 10, 13)
Cheatham Elec. Switching Device Co. (18)
Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp., (3, 10, 11)
Coeur d'Alenes Co., (17)
Compton Electrical Equipment Corp., (18)
Concrete Equipment Co., Inc., (6, 8, 15, 18)
Continental Conveyor & Equipment Co., (2, 6, 8, 15)
Control Products, Inc. (18)
Conveyor Components Co., (2, 18)
Crouse-Hinds Co., (18)
Dick Inc., R J., (6, 8)
Dodge Div., Reliance Electric Co., (6, 8)
Dowty Corp., (2, 6, 8, 9)
Duplex Mill & Mfg. Co., (6, 8)
Eaton Corp., Industrial Drives Div., (6, 8)
ELMAC Corp., (2, 5, 6, 7, 8, 18)
FMC Corp., Material Handling Equipment Div. (6, 8, 15)
Fafnir Bearing Div. of Textron Inc., (8)
Fairmont Supply Co., (6, 7, 8, 14)
Fastener House, Inc., (7)
Fenner America Ltd., (2, 5, 7)
Fenner, J H & Co., Ltd., (2, 5, 7, 13)
Ferro-Tech, Inc., (2)
Flexible Steel Lacing Co., (1, 2, 3, 5, 7, 11, 14)
Flood City Brass & Electric Co., (12)
GEC Mechanical Handling Ltd., (6, 8, 15)
General Electric Co., Industrial Sales Div., (18)
General Equipment & Mfg. Co., Inc., (18)
General Splice Corp., (1, 5, 7, 10, 11, 16)
Goodman Equipment Corp., (6, 8)
Goodrich, B F Engineered Systems Co., (4, 7, 11, 13, 16)
Goodyear Tire & Rubber Co., (7, 12, 13)
Greengate Industrial Polymers Ltd., (13)
Guyan Machinery Co., (6, 8)
Hammermills, Inc., Sub. of Pettibone Corp., (8)
Hayden-Nilos Conflow Ltd., (2, 7)
Heintz Manufacturers, Inc., (12, 13, 16)
Hewitt-Robins Conveyor Equipment Div. Litton Systems, Inc., (2)
Holz Rubber Co., A Randtron Div., (3, 4, 6, 7)
Huwood-Irwin Co., (2, 6, 8, 15)
Huwood Limited, (8)
Industrial Rubber Products Co., (1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 14, 16)
Iowa Manufacturing Co., (6, 7, 8)
Jabco, Inc. (18)
Jeffrey Mfg. Div., Dresser Industries Inc., (1, 2, 6, 8, 14, 15)
Kennedy Metal Products & Buildings, Inc., Jack, (18)
Kolberg Mfg. Corp., (2, 6, 8)
Lee Supply Co., Inc., (2, 10, 18)
Leman Machine Co., (6, 12)
Linatex Corp. of America, (2, 11)
Logan Corp., (1, 7, 8, 16)
Long-Airdox Co. A Div. of the Marmon Group, Inc., (7, 8, 9, 12, 13, 17)
Manson Services Inc., (1, 3, 4, 5, 6, 7, 8, 10, 11, 12, 13, 16, 17)
Marsh, E F, Engineering Co., (6, 8)
Martin Engrg. Co., (2, 14)
Material Control, Inc., (2)
MATO, (7)

McNally Pittsburg Mfg. Corp., (6, 9, 15)
Micro Switch, A Div. of Honeywell, (18)
Mineral Services Inc., (2)
Molded Dimensions Inc., (2)
National Mine Service Co., (7)
Owens Mfg., Inc., (6, 8, 14, 18)
Poly-Hi, Inc., (8)
Portec, Inc., Pioneer Div., (2, 6, 8, 14, 15)
Preiser/Mineco Div., Preiser Scientific Inc., (2)
Rema-Tech, (1, 3, 4, 10, 11, 12, 13)
Rexnord Inc., (2, 6, 8, 9, 14, 15)
Rexnord Inc., Process Machinery Div., (6, 8)
Rock Industries Machinery Corp., (2, 6)
Schaefer Brush Mfg. Co., (2)
Shaw-Almex Industries Ltd., (1, 16)
Shingle, L.H., Co., (1, 7, 10, 11, 13)
Stephens-Adamson, (2, 6, 8, 15)
Templeton, Kenly & Co., (14)
Unilok Belting Co., Div. of Georgia Duck and Cordage Mill, (7)
United States Steel Corp.
Van Gorp Mfg. Inc., (6, 8)
Vulcan Materials Co., Southeast Div., (12, 13, 16, 17)
Wajax Industries Ltd., (1, 5, 7)
Wallacetown Engineering Co. Ltd., (18)
Webb, Jervis B., Co., (6, 8, 9, 14, 15, 18)
Webster Mfg. Co., (8, 9)
West Virginia Armature Co., (6, 8, 11, 12, 18)
West Virginia Belt Sales & Repairs Inc., (1, 2, 5, 6, 7, 8, 10, 11, 12, 13, 14, 16)
Wilis & Paul Corp., The, (15)
Wilson, R. M., Co., (1, 2, 3, 6, 7, 8, 9)
Workman Developments, Inc., (2, 8)

CONVEYOR BELTING

Acme-Hamilton Mfg. Corp., Belting Div
Aggregates Equipment Inc
Baldwin Belting Inc
Banks-Miller Supply Co
Bonded Scale & Machine Co.
Boston Industrial Products Div., American Biltrite Inc.
CE Tyler Inc
Celanese Fibers Marketing Co
Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp.
Concrete Equipment Co., Inc
Dick Inc., R. J.
Dowty Corp.
Duplex Mill & Mfg. Co
Eaton Corp., Industrial Drives Div
ELMAC Corp.
Fairmont Supply Co
Fenner America Ltd
Fenner, J. H. & Co., Ltd
Ferro-Tech, Inc
Flexowall Corp.
Goodall Rubber Co
Goodrich, B. F.-Engineered Systems Co
Goodyear Tire & Rubber Co
Greengate Industrial Polymers Ltd
Holz Rubber Co., A Randron Div
Hewood-Irwin Co
Industrial Rubber Products Co
Iowa Manufacturing Co.
Lee Supply Co., Inc
Logan Corp.
Long-Airdox Co. A Div. of the Marmon Group, Inc
Manson Services, Inc
Mineral Services Inc
National Mine Service Co
Rost, H. & Co
Rubber Engineering & Mfg. Co
Scandura, Inc.
TBA Industrial Products Ltd
Trelleborg Rubber Co., Inc
Unilok Belting Co., Div. of Georgia Duck and Cordage Mill
Uniroyal, Inc
United States Steel Corp
Vulcan Materials Co., Southeast Div
Wajax Industries Ltd
West Virginia Belt Sales & Repairs Inc
Wilson, R. M., Co

CONVEYOR COVERS

Aggregates Equipment Inc
Armco Steel Corp., Product Info
Automatic Vulcanizers Corp
Baldwin Belting Inc
Barber-Greene Co
Bonded Scale & Machine Co
Continental Conveyor & Equipment Co
Iowa Manufacturing Co
Jeffrey Mfg. Div., Dresser Industries Inc
Kanawha Mfg. Co
Kolberg Mfg. Corp
Lee Supply Co., Inc
Linatex Corp. of America
Long-Airdox Co. A Div. of the Marmon Group, Inc
Marsh, E. F., Engineering Co.
Portec, Inc., Pioneer Div
Raychem Corp
Rexnord Inc., Process Machinery Div
Rock Industries Machinery Corp.
Trelleborg Rubber Co., Inc
Webb, Jervis B., Co
Webster Mfg. Co.
Wilson, R. M., Co

CONVEYOR GALLERIES, TUBULAR

Aggregates Equipment Inc
Continental Conveyor & Equipment Co
Fairfield Engineering Co
Industrial Contracting of Fairmont, Inc
Industrial Steel Co
Kanawha Mfg. Co
Lee Supply Co., Inc
Lively Mfg. & Equipment Co
Marsh, E. F., Engineering Co
McNally Pittsburg Mfg. Corp
Portec, Inc., Pioneer Div
Rock Industries Machinery Corp
Webb, Jervis B., Co
Wilson, R. M., Co

CONVEYOR-PULLEY LAGGING

Aggregates Equipment Inc
Automatic Vulcanizers Corp
Baldwin Belting Inc
Bonded Scale & Machine Co
Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp.
Concrete Equipment Co., Inc.
Dick Inc., R. J.
Dowty Corp
Durex Products, Inc., Natl. Wire Cloth Div
FMC Corp., Material Handling Equipment Div
Fairmont Supply Co.
General Splice Corp.
Goodall Rubber Co
Goodrich, B. F.-Engineered Systems Co
Goodyear Tire & Rubber Co.
Heintz Manufacturers, Inc
Holz Rubber Co., A Randron Div
Industrial Rubber Products Co
Lee Supply Co., Inc
Leman Machine Co.
Linatex Corp. of America
Manson Services, Inc
Marsh, E. F., Engineering Co
Rema-Tech
Rubber Engineering & Mfg. Co
Scandura, Inc
Van Gorp Mfg. Inc
Vulcan Materials Co., Southeast Div
West Virginia Belt Sales & Repairs Inc
Wilson, R. M., Co

CONVEYOR SKIRT BOARD

Acme Hamilton Mfg. Corp., Belting Div
Aggregates Equipment Inc
Automatic Vulcanizers Corp
Bonded Scale & Machine Co
Boston Industrial Products Div., American Biltrite Inc
CF Ehrsam
Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp
Concrete Equipment Co., Inc
Continental Conveyor & Equipment Co
Conveyor Components Co
Durex Products, Inc., Natl. Wire Cloth Div
Fairmont Supply Co
GEC Mechanical Handling Ltd
Goodrich, B. F.-Engineered Systems Co
Goodyear Tire & Rubber Co.
Hammermills, Inc., Sub. of Pettibone Corp
Holz Rubber Co., A Randron Div
Industrial Rubber Products Co
Iowa Manufacturing Co.
Kanawha Mfg. Co
Kolberg Mfg. Corp
Lee Supply Co., Inc
Linatex Corp. of America
Manson Services, Inc
Marsh, E. F., Engineering Co
Portec, Inc., Pioneer Div
Schaefer Brush Mfg. Co
Trelleborg Rubber Co., Inc
Webster Mfg. Co
West Virginia Belt Sales & Repairs Inc
Wilson, R. M., Co
Workman Developments, Inc

CONVEYOR WEIGHERS

Aggregates Equipment Inc
ASEA Inc
Auto Weigh Inc
Cardinal Scale Mfg. Co.
Fairbanks Weighing Div., Colt Industries
Fairfield Engineering Co
Howe Richardson Scale Co
Inflo Resometric Scale Inc
Jeffrey Mfg. Div., Dresser Industries Inc.
KHD Industrieanlagen AG, Humboldt Wedag
Kay-Ray Inc
Kilo-Wate Inc
K Tron Corp
Lively Mfg. & Equipment Co
Ohmart Corp
Ramsey Engineering Co
Revere Corp. of America, Sub. of Neptune Intl Corp
Rexnord Inc
Rexnord Inc., Process Machinery Div
Texas Nuclear
Thayer Scale Hyer Industries
Thurman Scale Co. Div. Thurman Mfg. Co
Webb, Jervis B., Co
Wilson, R. M., Co

CONVEYORS

1 APRON
2 ARMORED LONGWALL
3 BELT
4 BELT, EXTENSIBLE
5 BELT FEEDING
6 BUCKET
7 BUCKET-WHEEL
8 CABLE BELT
9 CHAIN & CHAIN & FLIGHT
10 DECLINE
11 DEWATERING
12 ELEVATING
13 ELEVATING, MINE TRANSFER CAR LOADING
14 MINE BRIDGE
15 MINE, FLEXIBLE-CHAIN
16 CHAIN, MOBILE-HEAD
17 PORTABLE
18 ROPE & BUTTON
19 SCREW
20 SECTIONAL
21 SHAKING, VIBRATING
22 SPIRAL LOWERING
23 STOCKPILING & RECOVERY

ASV Engineering Ltd., (3, 5, 9, 23)
Acco, Integrated Handling Systems Div., (3)
Acco Mining Sales Div., (2, 6, 7, 9)
Acco, Unit Conveyor Div., (3, 5, 17)
Aggregates Equipment Inc., (3, 6, 9, 17, 19, 21, 23)
Alpine Equipment Corp., (2, 3, 9)
American Alloy Steel, Inc
Anchor Conveyors Div., Standard Alliance Indus. Inc., (1, 3, 6, 9, 12)
Anderson Mavor (USA) Ltd., (2, 3, 4)
A-T-O Inc
Auto Weigh Inc., (3, 5)
Barber Greene Co., (3, 10, 12, 17, 18, 23)
Bonded Scale & Machine Co., (1, 3, 5, 9, 12)
British Jeffrey Diamond Div. of Dresser Europe S.A. (U.K. Branch), (2, 9, 12, 13, 17)
CE Ehrsam, (3, 5, 8, 9, 10, 12, 23)
CMI Corp., (3, 9, 12)
Cable Belt Conveyors Inc., (3, 8)
Campbell Chain Co., (9)
Canton Stoker Corp., (19, 21)
Card Corp., (3, 4, 8)
Carman Industries, Inc., (11, 21)
Certified Welding Services Inc
Cincinnati Mine Machinery Co., (9)

Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp. (3, 4, 12)
Concrete Equipment Co., Inc., (3, 12, 17, 19)
Connellsville Corp., (1, 6, 9, 11, 21)
Continental Conveyor & Equipment Co., (3, 5, 7, 10, 13, 17, 20, 23)
Crown Iron Works Co., (19)
Dennis Company, The, (9)
Dayton Automatic Stoker Co., (19)
DEMAG Lauchhammer (3, 5)
Deron R & D Co., Inc. (19)
Dosco Corp. (4, 14)
Dowty Corp. (2, 3, 4, 5, 9, 14)
Dravo Corp. (6, 7, 14, 18, 23)
Duplex Mill & Mfg. Co., (3, 6, 19)
Eickhoff America Corp., (2, 9)
ELMAC Corp. (3, 20)
Enterprise Fabricators, Inc., (6)
Eriez Magnetics, (1, 3, 5, 12, 17, 21)
ESCO Corp., (9)
FMC Corp., Link-Belt Material Handling Systems Div., (1, 3, 9, 10, 12, 14, 23)
FMC Corp., Material Handling Equipment Div., (12, 19, 21)
Fairchild, Inc., (3)
Fairfield Engineering Co., (1, 3, 4, 5, 6, 9, 10, 11, 12, 17, 19, 23)
Fairmont Supply Co., (6, 9, 12, 13, 15, 19)
Fate International Ceramic & Processing Equipment, Div. of the Fate-Root-Heath Co., a Banner Co., (3)
Feeco International, Inc., (3, 9, 10, 12, 17, 19, 23)
Fenner, J. H. & Co., Ltd., (3)
Ferro-Tech Inc. (3, 6, 12, 17)
Fletcher Sutcliffe Wild, Ltd., (3)
Fuller Co., A Gatx Co., (9)
GEC Mechanical Handling Ltd. (1, 3, 19, 21)
General Kinematics Corp., (21)
General Resource Corp., (19, 21)
Goodman Equipment Corp., (3, 4, 21)
Grinder CW Distributing Co., (11)
Gruendler Crusher & Pulverizer Co., (3, 12)
Hammermills, Inc., Sub. of Pettibone Corp., (3, 17, 23)
Hanson, R.A., Disc., Ltd.
Head Wrightson & Co. Ltd., (23)
Hemscheidt America, (2)
Hensel Mfg. Co., (1, 2, 9, 15, 17, 21, 22)
Hewitt-Robins Conveyor Equipment Div., Litton Systems, Inc. (3, 4, 8)
Heyl & Patterson, Inc., (7, 23)
Holmes Bros. Inc., (3, 6, 22)
Huwood-Irwin Co., (2, 3, 4, 5, 9, 13, 15)
Huwood Limited (2, 3, 4)
Industrial Contracting of Fairmont, Inc., (1, 3, 5, 6, 9, 12, 19, 20, 21, 22, 23)
Industrial Rubber Products Co., (1, 3, 5, 6, 9, 10, 12, 17, 19, 20)
Iowa Manufacturing Co., (3, 13, 17, 23)
Irwin-McKelvy Co., The, (3, 9, 21, 22, 23)
Janes Manufacturing Inc., (1, 9, 11, 12)
Jeffrey Mfg. Div., Dresser Industries Inc., (1, 3, 4, 5, 6, 7, 12, 17, 19, 20, 21, 22, 23)
Jeffrey Mining Machinery Div., Dresser Industries Inc., (9, 14, 15, 16, 17)
Jenkins of Retford Ltd., (3, 9, 23)
Joy Mfg. Co., (2, 4, 14)
Joy Mfg. Co. (U.K.) Ltd., (4, 14)
KHD Industrieanlagen AG, Humboldt Wedag, (3, 6, 19, 21)
Kaiser Engineers, Inc., (23)
Kanawha Mfg. Co., (1, 3, 4, 6, 9, 12, 18)
Kolberg Mfg. Corp., (3, 5, 23)
Lee-Norse Co., Sub. of Ingersoll-Rand Co., (14)
Lee Supply Co., Inc. (3, 11, 12)
Lively Mfg. & Equipment Co. (1, 3, 5, 23)
Long-Airdox Co. A Div. of the Marmon Group, Inc., (2, 3, 4, 5, 9, 10, 12, 13, 14, 16, 20, 23)
Machinoexport, (2, 9)
Manufacturers Equipment Co., The, (1, 3, 5, 6, 9, 12, 13, 19)
Marathon Mfg. Co., (3, 23)
Marsh, E. F., Engineering Co., (1, 3, 5, 6, 8, 10, 12, 13, 17, 20, 23)
McNally Pittsburg Mfg. Corp., (1, 3, 19, 22, 23)
Mineral Services Inc., (12)
Mining Equipment Mfg. Corp., (3)
Mining Machine Parts, Inc., (9)
Mining Progress, Inc., (2, 9)
Mining Supplies, Ltd. (2, 9, 15, 17)
Mintec/International, Div. of Barber-Greene, (3, 5, 7, 17, 23)
Myers-Whaley Co., (1, 3)
National Air Vibrator Co., (21)
National Iron Co., (1)
National Mine Service Co., (2, 9)
Ore Reclamation Co., (3, 19)
Owens Mfg., Inc., (3, 4, 5, 10)
Peerless Conveyor & Mfg. Co., Inc., (3, 5, 23)
Persingers Inc.
Portec, Inc., Pioneer Div., (1, 3, 5, 12, 17, 20, 23)
Rexnord Inc., (1, 3, 5, 6, 9, 12, 13, 21)
Rexnord Inc., Process Machinery Div., (3, 5, 6, 17)
Rish Equipment Co., Material Handling Systems Div.
Rock Industries Machinery Corp., (1, 3, 6, 17, 20, 23)
Rubber Engineering & Mfg. Co., (3, 6)
Sala International, (1, 2, 3)
Salem Tool Co., The, (12)
Savage, W. J. Co., (3)
Schroeder Bros. Corp., (3)
Serpentix Conveyor Corp., (3, 5, 10, 12, 13, 15, 17, 20, 22, 23)
Simplicity Engineering, (21)
Specialty Services, Inc., (3)
Sprout-Waldron, Koppers Co., Inc., (3, 6, 12, 19)
Stamler, W. R., Corp., The, (5, 12, 13)
Standard Metal Mfg. Co., (3, 5, 6, 12)
Stephens-Adamson, (1, 3, 13, 21, 23)
Sturtevant Mill Co., (19)
Telsmith Div., Barber-Greene Co., (3, 5, 17, 23)
Underground Mining Machinery Ltd., (2)
UniRoc Limited
Unlock Belting Co., Div. of Georgia Duck and Cordage Mill, (3)
Universal Industries, (3, 6, 12)
Universal Road Machinery Co., (3, 6)
Vibco Inc., (21)
Vibranetics, Inc., (12, 21)
Vibra-Screw Inc., (5, 21)
Wajax Industries Ltd., (2, 3, 4, 9, 15, 20, 23)
Webb, Jervis B., Co., (1, 3, 4, 5, 6, 8, 9, 10, 12, 17, 18, 19, 20, 21, 23)
Webster Mfg. Co., (1, 3, 5, 6, 9, 10, 12, 13, 19, 20, 21, 23)
West Virginia Armature Co., (3, 4, 8, 14)
West Virginia Belt Sales & Repairs Inc., (1, 3, 6, 9, 12, 21)
Willis & Paul Corp., The, (3, 5, 6, 9, 10, 12, 19, 20, 23)
Wilmot Engineering Co., (9, 12)
Wilson, R. M., Co., (1, 3, 5, 6, 9, 10, 11, 12, 13, 17, 18, 19, 20, 21, 23)

CRUSHER REPLACEMENT PARTS

Allis-Chalmers
Allis-Chalmers, Crushing & Screening Equipment
American Pulverizer Co.
Amsco Div., Abex Corp.
Birdsboro Corp.
British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch)
Columbia Steel Casting Co., Inc.
Eagle Crusher Co., Inc.
ESCO Corp.
Fairmont Supply Co.
Frog Switch Mfg. Co.
Hammermills, Inc., Sub. of Pettibone Corp.
Iowa Manufacturing Co.
Jeffrey Mfg. Div., Dresser Industries Inc.
Laubenstein Mfg. Co.
Manufacturers Equipment Co., The
McLanahan Corp.
Pennsylvania Crusher Corp.
Pettibone Corp.
Portec, Inc., Pioneer Div.
Resisto-Loy Co.
Rexnord Inc., Process Machinery Div.
Rock Industries Machinery Corp.
Steel Heddle Mfg. Co., Industrial Div.
Telsmith Div., Barber-Greene Co.
Thomas Foundries Inc.
Williams Patent Crusher & Pulv. Co.
Wilson, R. M., Co.

CRUSHERS

1 HAMMER
2 IMPACT
3 JAW
4 LABORATORY
5 RING
6 ROLL
7 MULTISTAGE

Aggregates Equipment Inc., (3)
Allis-Chalmers, (3)
Allis-Chalmers, Crushing & Screening Equipment, (2, 3)
American Pulverizer Co., (1, 2, 4, 5, 6)
Aroster Mine & Smelter Supply (4)
Barber-Greene Co., (3, 6)
Birdsboro Corp., (3)
Bonded Scale & Machine Co. (6)
British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch), (1, 2, 4, 6)
Duplex Mill & Mfg. Co., (1, 6)
Eagle Crusher Co., Inc., (1, 2, 3, 6, 7)
El-Jay, Inc.
Fairmont Supply Co., (1, 2, 7)
Fate-International Ceramic & Processing Equipment, Div. of the Fate-Root-Heath Co., a Banner Co., (6)
Frog Switch Mfg. Co., (2)
Fuller Co., A Gatx Co., (3, 6)
GEC Mechanical Handling Ltd., (1, 2, 3, 5, 6)
Gruendler Crusher & Pulverizer Co., (1, 2, 3, 4, 5, 6, 7)
Gundlach, T. J., Machine Co., Div. J. M. J. Industries, Inc., (2, 6, 7)
Hammermills, Inc., Sub. of Pettibone Corp., (1, 2, 3, 4, 6)
Hemscheidt America, (3)
Hensley Industries Inc., (5)
Hewitt-Robins Div., Litton Systems, Inc., (1, 2, 3)
Holmes Bros. Inc., (4)
Iowa Manufacturing Co., (1, 2, 3, 6)
Jeffrey Mfg. Div., Dresser Industries Inc., (1, 2, 7)
Joy Mfg. Co., Denver Equipment Div., (3, 4, 6)
KHD Industrieanlagen AG, Humboldt Wedag, (1, 2, 3, 4, 5, 6)
Koppers Co., Inc., (1, 2, 5, 6, 7)
Koppers Co., Inc., Metal Products Div., Hardinge Operation, (1, 2, 5, 6)
Machinoexport, (1, 3, 6)
Mauc Div., Donaldson Co., (2)
Manufacturers Equipment Co., The
McLanahan Corp. (3, 6, 7)
McNally Pittsburg Mfg. Corp., (6)
Mine & Smelter Industries, (3, 4)
Mineral Services Inc., (6)
Mining Progress, Inc., (3, 6, 7)
Morse Bros. Machinery Co., (3, 4)
Owens Mfg., Inc., (2)
Pennsylvania Crusher Corp., (1, 2, 3, 4, 5, 6, 7)
Portec, Inc., Pioneer Div., (1, 2, 3, 6, 7)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 3, 4)
Pulverizing Machinery, Div. of MikroPul Corp., (1, 2, 4)
Resisto-Loy Co., (3)
Rexnord Inc., Process Machinery Div., (1, 2, 3, 6)
Rish Equipment Co. Intl.
Rish Equipment Co., Material Handling Systems Div.
Rock Industries Machinery Corp., (1, 2, 3, 6)
S & S Machinery Sales, Inc., (2)
Sala International, (4)
Schroeder Bros. Corp., (6)
Simplicity Engineering, (1, 2)
Smico Corp., (1)

Soiltest, Inc., (4)
Sprout Waldron, Koppers Co., Inc., (1, 6)
Stedman Fdy. & Mach. Co. (1, 2, 4, 5, 6, 7)
Steel Heddle Mfg. Co., Industrial Div., (1, 2, 5)
Straub Mfg. Co., (3)
Sturtevant Mill Co., (1, 2, 3, 4, 5, 6)
Telsmith Div., Barber-Greene Co., (3, 6)
Universal Road Machinery Co., (3)
Williams Patent Crusher & Pulv. Co., (1, 2, 4, 5, 6)
Wilmot Engineering Co., (6)
Wilson, R. M., Co., (2, 4, 6, 7)
Workman Developments, Inc., (4)

CRUSHING PLANTS, PORTABLE

Aggregates Equipment Inc.
Allis-Chalmers
Allis-Chalmers, Crushing & Screening Equipment
Barber-Greene Co.
British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch)
Eagle Crusher Co., Inc.
El Jay, Inc.
GEOMIN
Gruendler Crusher & Pulverizer Co.
Hammermills, Inc., Sub. of Pettibone Corp.
Hanson, R.A., Disc., Ltd.
Hewitt-Robins Div., Litton Systems, Inc.
Industrial Contracting of Fairmont, Inc.
Iowa Manufacturing Co.
Jeffrey Mfg. Div., Dresser Industries Inc.
KHD Industrieanlagen AG, Humboldt Wedag
Logan Corp.
McDowell-Wellman Engrg. Co.

Mintec/International, Div. of Barber-Greene
Pennsylvania Crusher Corp.
Portec, Inc., Pioneer Div.
Rexnord Inc., Process Machinery Div.
Rish Equipment Co. Intl
Rish Equipment Co., Material Handling Systems Div.
Rock Industries Machinery Corp.
Stedman Fdy. & Mach. Co.
Straub Mfg. Co.
Telsmith Div., Barber-Greene Co.
Wilson, R. M., Co.

CRUSHING & SCREENING PLANTS, PORTABLE

Aggregates Equipment Inc.
Allis-Chalmers
Allis-Chalmers, Crushing & Screening Equipment
Barber Greene Co.
British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch)
Eagle Crusher Co., Inc.
El-Jay, Inc.
GEOMIN
Gruendler Crusher & Pulverizer Co.
Hammermills, Inc., Sub. of Pettibone Corp.
Hanson, R.A., Disc., Ltd.
Hewitt-Robins Div., Litton Systems, Inc.
Industrial Contracting of Fairmont, Inc.
Iowa Manufacturing Co.
Jeffrey Mfg. Div., Dresser Industries Inc.
KHD Industrieanlagen AG, Humboldt Wedag
Logan Corp.
Machinoexport
McDowell-Wellman Engrg. Co.
Mintec/International, Div. of Barber-Greene
Portec, Inc., Pioneer Div.
Rexnord Inc., Process Machinery Div.
Rock Industries Machinery Corp.
Stedman Fdy. & Mach. Co.
Straub Mfg. Co.
Telsmith Div., Barber-Greene Co.
Wilson, R. M., Co.

CYCLONES, DUST COLLECTING

Aerofall Mills Ltd.
American Air Filter Co., Inc.
American Alloy Steel, Inc.
American Standard, Industrial Products Div.
C-E Raymond/Bartlett-Snow, Div. Combustion Engineering, Inc.
CMI Corp.
CSE Mine Service Co.
Carborundum Company
Donaldson Co., Inc.
Ducon Co., Inc., The
Duplex Mill & Mfg. Co.
Ferro-Tech, Inc.
Fuller Co., A Gatx Co.
General Resource Corp.
Industrial Contracting of Fairmont, Inc.
Iowa Manufacturing Co.
KHD Industrieanlagen AG, Humboldt Wedag
Linatex Corp. of America
McNally Pittsburg Mfg. Corp.
NFE International Ltd.
Process Equipment, Stansteel Corp.
Research-Cottrell, Inc.
Sprout-Waldron, Koppers Co., Inc.
Unifloc Limited
Western Precipitation Div., Joy Mfg. Co.

CYCLONES, HEAVY MEDIUM

(SEE WASHERS)

CYCLONES WATER TREATMENT

American Alloy Steel, Inc.
Cyclone Machine Corp.
Daniels Company, The
Dorr Oliver Long, Ltd.
Dravo Corp.
Heil Process Equipment Co., Div. of Dart Industries, Inc.
Heyl & Patterson, Inc.
Krebs Engineers
McNally Pittsburg Mfg. Corp.
Mineral Services Inc.
Sala International
Telsmith Div., Barber-Greene Co.
Unifloc Limited
WEMCO Div., Envirotech Corp.

CYLINDERS

1. ELECTRIC
2. HYDRAULIC

Anixter Mine & Smelter Supply, (2)
A-T-O Inc., (2)
Bruning Co., (2)
ENERPAC, Div. of Applied Power Inc., (2)
Fairmont Supply Co., (2)
Gullick Dobson Intl. Ltd., (2)
Guyan Machinery Co., (2)
HYCO, Inc., Sub. of The Weatherhead Co., (2)
Iowa Industrial Hydraulics, Inc., (2)
Lebco, Inc., Illinois Div., (2)
Marion Co., Div. of Sycon Corp., (2)
McDowell-Wellman Engrg. Co., (2)
Mining Equipment Mfg. Corp., (2)
Porter, H. K., Inc., (2)
Raco International, Inc., (1)
Rexnord Inc., (2)
Templeton, Kenly & Co., (2)
Tel-O-Matic, (2)
WABCO Fluid Power Div., an American Standard Co., (2)
Ward Hydraulics Div., ATO Corp., (2)
Weatherhead Co., The, (2)
Wilson, R. M., Co., (1)

DENSITY MEASUREMENT & CONTROL

Automation Products, Inc.
Beckman Instruments, Inc.
Daniels Company, The
Halliburton Services-Research Center
Kay-Ray Inc.
K-Tron Corp.
Mine & Smelter Industries
Ohmart Corp.
Preiser/Mineco Div., Preiser Scientific Inc.
Texas Nuclear
TOTCO Div.-Baker Oil Tools, Inc.
Wilmot Engineering Co.

DEPRESSANTS

Preiser/Mineco Div., Preiser Scientific Inc.

DRIVES

1. ADJUSTABLE & SELECTIVE SPEED
2. BELT
3. CHAIN
4. FLANGE-MOUNTED
5. FLUID, HYDRAULIC
6. GEAR, WORM-GEAR
7. SHAFT-MOUNTED
8. V-BELT
9. VARIABLE-SPEED
10. VARIABLE SPEED, HYDRAULIC
11. EDDY-CURRENT

Allen-Bradley Co., (1, 9)
Allis-Chalmers, (1)
American Poclain Corp., (5, 10)
American Standard, Industrial Products Div., (1, 2, 5)
Banner Bearings, (1, 2, 3, 6, 8, 9)
Big Sandy Electric & Supply Co., Inc., (1, 2, 3, 4, 5, 6, 7, 8, 9)
Bonded Scale & Machine Co., (2, 3, 6, 7)
Boston Industrial Products Div., American Biltrite Inc., (2, 8, 9)
Browning Mfg. Div., Emerson Electric Co., (2, 3, 6, 7, 8, 9)
CSE Mine Service Co., (2)
Coeur d'Alenes Co., (1, 2, 5, 6, 7, 9, 10, 11)
Compton Electrical Equipment Corp., (1, 11)
Cone Drive Gears, A Unit of Ex-Cell-O Corp., (4, 6, 7)
Continental Conveyor & Equipment Co., (7)
Controlled Systems Inc., (1, 2, 9)
Cutler-Hammer, Inc., (1, 9)
Dayco Corp., Rubber Products Div., (1, 2, 8, 9)
Dick Inc., R. I., (1, 2, 8, 9)
Dodge Div., Reliance Electric Co., (2, 3, 4, 5, 7, 8)
Dominion Engineering Works Ltd., (6, 7)
Dowty Corp., (2, 4, 9)
Duplex Mill & Mfg. Co., (2, 3, 7, 8, 9)
Dynex Div., Applied Power Inc., (5, 10)
Eaton Corp., World Headquarters, (1, 2, 4, 5, 6, 7, 8, 9)
Eaton Corp., Industrial Drives Div., (1, 2, 4, 6, 7, 8, 9, 11)
Electric Machinery Mfg. Co., (1, 9, 11)
FMC Corp., Drive Div., (1, 5, 6, 7, 9)
FMC Corp., Pump Div., (5, 9, 10)
Fairmont Supply Co., (1, 2, 3, 4, 6, 7, 8, 9)
Falk Corp., The, (1, 4, 5, 6, 7, 9, 10)
Federal Supply & Equipment Co., Inc., (5)
Fluidrive Engineering Co. Ltd., (5, 10)
Formsprag Co., (5, 9)
GEC Mechanical Handling Ltd., (10)
GTE Sylvania Inc., (1, 9)
Gates Rubber Co., The, (1, 8)
General Electric Co., DC Motor & Generator Dept., (1)
General Electric Co., Industrial Sales Div., (1, 2, 3, 4, 6, 7, 8, 9, 11)
Goodman Equipment Corp., (2)
Harnischfeger Corp., (1)
Huwood Irwin Co., (2, 3, 6)
Huwood Limited, (1, 2, 3, 4)
Illinois Gear/Wallace Murray Corp., (6)
Industrial Rubber Products Co., (1, 2, 3, 6, 7, 8, 9)
Kanawha Mfg. Co.
Koppers Co., Inc., (1, 7, 9)
Leeds & Northrup Co., (9)
Lee Supply Co., Inc., (9)
Lima Electric Co., Inc., (1)
Logan Corp., (2, 3, 6, 7, 8, 9)
Louis Allis Div., Litton Industrial Products Inc., (1, 2, 3, 4, 6, 8, 9, 11)
Lucas Industries, Fluid Power Div., (5, 10)
Mining Progress, Inc., (1, 4, 5, 7)
Mining Supplies Ltd., (3, 4)
Morse Chain Div. of Borg-Warner Corp., (1, 2, 3, 6, 7, 9)
National Iron Co., (7)
Owens Mfg., Inc., (2)
Philadelphia Gear Corp., (1, 6, 7, 9, 10)
Power Transmission Div., Dresser Industries, Inc., (1, 2, 4, 6, 7, 9)
Raco International, Inc., (1)
Reliance Electric Co., (1, 2, 4, 6, 8, 9, 11)
Rexnord Inc., (3, 5)
Robbins & Myers, Inc., (1, 4, 6, 7, 9)
Robicon Corp., (9)
Rockwell Standard Div., Rockwell International Corp., (6)
Sperry Vickers Div., Sperry Rand Corp., (1, 5, 10)
Sperry Vickers, Tulsa Div., (4, 6, 7)
Steel Heddle Mfg. Co., Industrial Div., (1, 2, 9)
Sterling Power Systems, Inc., A Sub. of The Lionel Corp., (4, 6, 9)
Tool Steel Gear & Pinion Co., (6)
Twin Disc, Inc., (1, 5)
U. S. Electrical Motors Div. Emerson Electric Co., (1, 4, 6, 7, 9, 11)
Webb, Jervis B., Co.
West Virginia Armature Co., (2)
West Virginia Belt Sales & Repairs Inc., (2, 3)
Westinghouse Electric Corp., (1, 6, 9)
Wichita Clutch Co., Inc., (9)
Wilmot Engineering Co., (8)
Wood's, T. B., Sons Co., (1, 2, 7, 8, 9, 10)

DRYERS

1. CENTRIFUGAL
2. CENTRIFUGAL, SOLID BOWL
3. COAL, STEAM-PROCESS
4. THERMAL
5. THERMAL, CONTINUOUS ROTARY
6. THERMAL, FLUIDIZED-BED
7. CENTRIFUGAL, VIBRATING

Aggregates Equipment Inc., (5)
Allis-Chalmers, (5)
Anictex, (1, 2, 5, 6)
Bethlehem Steel Corp., (1, 2)
Bird Machine Co., Inc., (1, 2, 7)
C-E Raymond/Bartlett Snow, Div. Combustion Engineering, Inc., (4, 5, 6)
Centrifugal & Mechanical Industries, Inc., (1, 2, 7)
Dorr-Oliver Inc., (6)
Envirotech Corp., Eimco BSP Div., (4, 5)

FMC Corp., Link Belt Material Handling Systems Div., (5, 6)
Fairmont Supply Co., (1)
Feeco International, Inc., (5)
Fuller Co., A Gatx Co., (6)
GEC Mechanical Handling Ltd., (5)
Heyl & Patterson, Inc., (1, 4, 6, 7)
Holmes Bros. Inc., (4)
Indiana Steel & Fabricating Co., (4)
Irvin McKelvy Co., The, (5)
Jeffrey Mfg. Div., Dresser Industries Inc., (4, 6)
Johnson Div., Universal Oil Products, (3)
Joy Mfg. Co., Denver Equipment Div., (4)
K G Industries, Inc., (4, 5, 6)
KHD Industrieanlagen AG, Humboldt Wedag, (6)
Kennedy Van Saun Corp., Sub. of McNally Pittsburg, (5, 6)
Koch Engineering Co., Inc., (6)
Koppers Co., Inc., Metal Products Div., Hardinge Operation, (3, 5)
Laubenstein Mfg. Co., (1)
Lively Mfg. & Equipment Co., (1, 4)
McDowell-Wellman Engrg. Co., (5)
McNally Pittsburg Mfg. Corp., (1, 4, 6, 7)
Pell Corp., (3, 4)
Patterson-Kelley Co., Div. of Taylor Wharton Co. - Harsco Corp., (5)
Portec, Inc., Pioneer Div., (5)
Process Equipment, Stansteel Corp., (5)
Sala International, (5)
Stearns-Roger Inc., (5)
WEMCO Div., Envirotech Corp., (7)
Whiting Corp., (5, 6)
Wemco Engineering Co., (5)

DUCT, AIR

American Alloy Steel, Inc
Armco Steel Corp., Product Info
Davis Instrument Mfg. Co
Fairmont Supply Co
Federal Metal Hose Corp
Fiberglass Resources Corp
Flexaust Co., Div. of Callahan Mining
Heil Process Equipment Co., Div. of Dart Industries, Inc
ITT Holub Industries
Industrial Rubber Products Co
Johnston-Morehouse-Dickey Co
Kanawha Mfg. Co
Lee Supply Co., Inc
Logan Corp
National Mine Service Co
Peabody ABC
Porter, H.K. Co., Inc
Preiser/Mineco Div., Preiser Scientific Inc
Schauenburg Flexadux Corp
United McGill Corp
Wajax Industries Ltd
West Virginia Belt Sales & Repairs Inc.
Wilson, R. M., Co

DUST-COLLECTOR BAGS, TUBES

Aerofall Mills Ltd
Aggregates Equipment Inc
Air Correction Div., - UOP
American Air Filter Co., Inc
Bemis Co., Inc
C-E Raymond/Bartlett-Snow, Div. Combustion Engineering, Inc
Daniels, C. R., Inc
Fairmont Supply Co
Ferro-Tech, Inc
Firestone Tire & Rubber Co
Johnson-March Corp., The
KHD Industrieanlagen AG, Humboldt Wedag
Logan Corp
MikroPul Corp
Mine Safety Appliances Co
National Filter Media Corp
Peabody ABC
Preiser/Mineco Div., Preiser Scientific Inc
Smico Corp
Sprout-Waldron, Koppers Co., Inc.
Standard Metal Mfg. Co
Torit Div. Donaldson Co. Inc
Wheelabrator-Frye Inc., Air Pollution Control Div
Wilson, R. M., Co
Wire Cloth Enterprises, Inc

DUST COLLECTORS, COAL HANDLING, PREPARATION

Aggregates Equipment Inc
Air Pollution Control Operations, FMC Corp
American Air Filter Co., Inc
American Alloy Steel, Inc
American Standard, Industrial Products Div
CSE Mine Service Co
Donaldson Co., Inc
Dravo Corp
Ducon Co., Inc., The
Environeering, Inc
Fairchild, Inc
Ferro-Tech, Inc
Fuller Co., A Gatx Co
General Resource Corp
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc
Johnson-March Corp., The
Joy Mfg. Co
Joy Mfg. Co. (U.K.) Ltd
KHD Industrieanlagen AG, Humboldt Wedag
Kanawha Mfg. Co
Krebs Engineers
McNally Pittsburg Mfg. Corp
MikroPul Corp
Mineral Services Inc
Peabody ABC
Preiser/Mineco Div., Preiser Scientific Inc
Research Cottrell, Inc
Sly, W. W., Mfg. Co
United McGill Corp
Vortex Air Corp
West Virginia Belt Sales & Repairs Inc
Western Precipitation Div., Joy Mfg. Co
Wheelabrator-Frye Inc., Air Pollution Control Div
Willis & Paul Corp., The
Wilson, R. M., Co

DUST COLLECTORS, SHOP, LABORATORY, ETC.

Aggregates Equipment Inc
Air Correction Div., - UOP
American Air Filter Co., Inc
American Standard, Industrial Products Div
Ducon Co., Inc., The
Environeering, Inc
Fairchild, Inc
Ferro-Tech, Inc
Fil-T-Vac Corp
Fisher Scientific Co
General Resource Corp
Heil Process Equipment Co., Div. of Dart Industries, Inc
ITT Holub Industries
Johnson-March Corp., The
MikroPul Corp
National Mine Service Co
Research-Cottrell, Inc
Rockwell International, Power Tool Div
Sly, W. W., Mfg. Co
Sprout-Waldron, Koppers Co., Inc
Torit Div. Donaldson Co. Inc
United McGill Corp
Wheelabrator-Frye Inc., Air Pollution Control Div

DUST-CONTROL & DUSTPROOFING EQUIPMENT & LIQUID COMPOUNDS

Adams Equipment Co., Inc
Aquadyne, Div. of Molomco, Inc
Communication & Control Eng. Co. Ltd
Deron R & D Co., Inc
Donaldson Co., Inc
Dowell Div. of the Dow Chemical Co
Ferro-Tech, Inc
Grindex-CWI Distributing Co
Hayden Nilos Conflow Ltd
Houghton & Co., E. F.
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc
Johnson-March Corp., The
Nalco Chemical Co
National Mine Service Co
Preiser/Mineco Div., Preiser Scientific Inc
Shell Chemical Co., Chemical Sales
Sly, W. W., Mfg. Co

Spraying Systems Co
Trelleborg Rubber Co., Inc
Uniroyal, Inc
Viking Oil & Machinery Co
Wen-Don Corp
Wilson, R. M., Co

ENGINEERS

1 BLASTING-VIBRATION
2 ELECTRICAL
3 FACILITY DESIGN & CONSTRUCTION
4 FLOTATION
5 GEOLOGY
6 INDUSTRIAL
7 MECHANICAL
8 MINING
9 PREPARATION
10 STRIPPING
11 MINE-MANAGEMENT
12 GEOTECHNICAL (SOIL AND ROCK MECHANICS, SLOPE STABILITY)
13 CIVIL
14 DAMS
15 ARCHITECTURE

Aggregates Equipment Inc., (2, 3, 6, 7, 13)
Allen & Garcia Co., (2, 3, 7, 9, 13)
Atlas Powder Co., (1)
Atlas Railroad Construction Co., (13)
Austin Powder Co., (1)
Badger Construction Co., Div. of Melton Stuart Co., (3, 9)
Barnes & Reinecke, Inc., (2, 3, 6, 7, 13)
Beaumont, Edward C., (5, 6)
Betz Laboratories, (3)
Blaw-Knox Equipment, Inc., (3)
Boggess, B. L., Co., Mine Development Group
Boyd, John T. Co., (5, 8, 9, 10, 11)
British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch), (2, 6, 7, 8)
Brown Mining Construction Co., (3)
Catalytic, Inc., (3)
Cementation Co. of America, Inc., (3, 8)
Cementation Mining Ltd., (3, 5, 7, 8, 12, 13, 14)
Collins Radio, (2)
Commercial Testing & Engineering Co., (4, 8, 9)
Compton Electrical Equipment Corp., (2)
Continental Conveyor & Equipment Co., (2, 3, 7, 8, 9, 13)
Daniels Company, The, (3, 4, 7, 9)
Davis, J. J., Associates, Inc., (6, 8, 9, 11)
Dover Conveyor & Equipment Co., Inc., (2, 7)
Dowell Div. of the Dow Chemical Co., (9)
Dravo Corp., (3, 9)
du Pont de Nemours, E. I. & Co. Inc
Envirosphere Co
FMC Corp., Link-Belt Material Handling Systems Div., (9)
Fairfield Engineering Co., (2, 7)
Feeco International, Inc., (3)
Ferguson, H.K., Co., (3)
Ferro Tech, Inc., (3, 6, 9)
Fullerton, Hodgart & Barclay Ltd., (7)
GEC Mechanical Handling Ltd., (3, 7, 9)
Galigher Co., The, (3)
Gates Engr. Co., (3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15)
Geometrics, (5, 12)
GEOMIN, (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14)
Golder Associates, Inc., (5, 8, 11, 12, 13)
Hammermills, Inc., Sub. of Pettibone Corp., (3)
Hanson, R.A., Disc., Ltd
Hazen Research, Inc., (4, 5, 9)
Head Wrightson & Co. Ltd., (9)
Hewitt-Robins Conveyor Equipment Div., Litton Systems, Inc., (8)
Hewitt Robins Div., Litton Systems, Inc., (3, 7, 8)
Heyl & Patterson, Inc., (3, 4, 9)
Holley, Kenney, Schott, Inc., (2, 3, 6, 7, 9, 13)
Industrial Contracting of Fairmont, Inc., (3, 7, 9)
Irvin-McKelvy Co., The, (3, 9)
Jenkins of Retford Ltd., (2, 3, 4, 6, 7, 9, 13)
Joy Mfg. Co., Denver Equipment Div., (4)
Kaiser Engineers, Inc., (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15)
Kilborn-NUS, Inc., (3, 6, 7, 8, 9, 10)
Lake Shore, Inc., (2, 3, 7)
Lively Mfg. & Equipment Co., (3, 9)
Loftus, Peter F., Corp., (2, 3, 6, 7, 8, 13, 15)
MacDonald Engineering Co., (2, 3, 6, 7, 13)
Mathews, Abe W., Engineering Co., (2, 3, 7, 13, 15)
McDowell-Wellman Engrg. Co., (3, 6, 7, 8, 10, 13)

McKee, Arthur G. & Co., Western Knapp Eng. Div., (3, 4, 7, 8, 9, 13)
McNally Pittsburg Mfg. Corp., (9)
Mine Engineering & Development Co. (MEDCO), (5, 8, 10, 11, 13, 14)
Mineral Services Inc., (3, 4, 5, 8, 9, 11)
Minerals Processing Co., Div. of Trojan Steel Co., (3, 9)
Mintec/International, Div. of Barber-Greene, (3)
Montreal Engineering Co. Ltd., (2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15)
Multi-Amp Corp., (2)
National Electric Coil Div. of McGraw-Edison Co., (2)
NUS Corp., Robinson & Robinson Div., (3, 7)
O'Donnell & Associates, Inc., (1, 7)
ORBA Corp., (9, 13)
Patent Scaffolding Co., (3)
Preiser/Mineco Div., Preiser Scientific Inc., (4, 8, 9)
Pullman Torkelson Co., (2, 3, 6, 7, 9, 13)
Roberts & Schaefer Co., (3, 9)
Roller Corp., (9)
Rust Engineering Co., A Sub. of Wheelabrator-Frye Inc., (2, 3, 6, 7, 13, 15)
Sala International, (4)
Stearns-Roger Inc., (2, 3, 6, 7, 8, 9, 15)
Stephens-Adamson, (3)
Treadwell Corp., (2, 3, 6, 7, 13)
VME-Nitro Consult, Inc., (1, 8, 11)
Webb, Jervis B., Co., (3)
Weir, Paul Co., Inc., (3, 4, 5, 8, 9, 10, 11)
West Virginia Armature Co., (2, 7)
Westinghouse Electric Corp., (2)
Willis & Paul Corp., The, (3, 7, 12, 13)
Wilson Engineering Co., (3)
Wilmot Engineering Co., (9)

EYE SHIELDS

AO Safety Products, Div. of Amer. Optical Corp
American Optical Corp
Anixter Mine & Smelter Supply
Bowman Distribution, Barnes Group, Inc
CSE Mine Service Co
Fairmont Supply Co
Fibre-Metal Products Co
Fire Protection Supplies Inc
General Scientific Equipment Co
Industrial Rubber Products Co
Martindale Electric Co
Mine Safety Appliances Co
National Mine Service Co
Preiser/Mineco Div., Preiser Scientific Inc
Shannon Optical Co., Inc
Welsh Div. of Textron
Wilson Products Div., ESB, Inc

FABRICATORS, BINS, TANKS & HOPPERS

Aggregates Equipment Inc
American Alloy Steel, Inc
Asbury Industries, Inc
Bethlehem Steel Corp
Concrete Equipment Co., Inc
Continental Conveyor & Equipment Co
Easton Car & Construction Co
Enterprise Fabricators, Inc
Equipment Mfg. Services, Inc
Fairfield Engineering Co
Ferro-Tech, Inc
Holmes Bros. Inc
Huwood-Irwin Co
Industrial Contracting of Fairmont, Inc
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc
Industrial Steel Co
Kanawha Mfg. Co
Lake Shore, Inc
Laubenstein Mfg. Co
Leman Machine Co
Lively Mfg. & Equipment Co
Mathews, Abe W., Engineering Co
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Midwest Steel Div., Midwest Corp
Mining Supplies, Ltd
Ore Reclamation Co
Rise Corp
Somerset Welding & Steel Inc
Specialty Services, Inc
Standard Metal Mfg. Co
Sturtevant Mill Co
Trelleborg Rubber Co., Inc
Uniroyal, Inc
United States Steel Corp

Webb, Jervis B., Co
West Virginia Belt Sales & Repairs Inc
Willis & Paul Corp., The
Wilmot Engineering Co
Wilson, R. M., Co
Workman Developments, Inc

FABRICATORS, STEEL & STRUCTURE

Aggregates Equipment Inc
Babcock & Wilcox
Blaw-Knox Equipment, Inc
Brown Mining Construction Co
Canton Stoker Corp
Coeur d'Alenes Co
Continental Conveyor & Equipment Co
Dover Conveyor & Equipment Co., Inc
Dowty Corp
Dravo Corp
Enterprise Fabricators, Inc
Equipment Mfg. Services, Inc
Fairfield Engineering Co
Fath Corp., The
Greenbank Cast Basalt Eng. Co. Ltd
Huwood-Irwin Co
Industrial Contracting of Fairmont, Inc
Industrial Steel Co
Jennmar Corp
Kanawha Mfg. Co
Lake Shore, Inc
Leman Machine Co
Lively Mfg. & Equipment Co
Manson Services, Inc
Mathews, Abe W., Engineering Co
McDowell-Wellman Engrg. Co
McLanahan Corp
Midwest Steel Div., Midwest Corp
Mining Equipment Mfg. Corp
Mining Supplies, Ltd
Ore Reclamation Co
Rise Corp
Sanford-Day/Marmon Transmotive, Div. of the Marmon Group, Inc
Somerset Welding & Steel Inc
Specialty Services, Inc
Standard Metal Mfg. Co
Sturtevant Mill Co
United States Steel Corp
Willis & Paul Corp., The
Wilson, R. M., Co

FACE SHIELDS

AO Safety Products, Div. of Amer. Optical Corp
American Optical Corp
Anixter Mine & Smelter Supply
Bowman Distribution, Barnes Group, Inc
Bullard, E. D. Co
CSE Mine Service Co
Fairmont Supply Co
Fire Protection Supplies Inc
General Scientific Equipment Co
Industrial Rubber Products Co
Lincoln Electric Co., The
3 M Co
Martindale Electric Co
Mine Safety Appliances Co
Mining Equipment Mfg. Corp
Preiser/Mineco Div., Preiser Scientific Inc
Shannon Optical Co., Inc
Snap-On Tools Corp
Welsh Div. of Textron
Willson Products Div., ESB, Inc

FAN SIGNALS

General Equipment & Mfg. Co., Inc
Huwood-Irwin Co
Jabco, Inc
Jeffrey Mining Machinery Div., Dresser Industries Inc
Lee Supply Co., Inc
National Mine Service Co
Pyott-Boone, Inc

FANS, BLOWING, EXHAUST

American Air Filter Co., Inc
American Standard, Industrial Products Div
CSE Mine Service Co
Dresser Industries, Inc., Industrial Products Div
Fairmont Supply Co
Fuller Co., A Gatx Co

General Resource Corp
Guyan Machinery Co
Heil Process Equipment Co., Div. of Dart Industries, Inc
ITT Holub Industries
K.G. Industries, Div. of Carrier Corp
Jeffrey Mining Machinery Div., Dresser Industries Inc
Joy Mfg. Co
KHD Industrieanlagen AG, Humboldt Wedag
Koppers Co., Inc
Manufacturers Equipment Co., The
Mathews, Abe W., Engineering Co
New York Blower Co
Peabody ABC
Porter, H.K. Co., Inc
Preiser/Mineco Div., Preiser Scientific Inc
Robinson Industries, Inc
Schauenburg Flexadux Corp
Sprout-Waldron, Koppers Co., Inc
Westinghouse Electric Corp

FANS, VENTILATING

CSE Mine Service Co
Fairmont Supply Co
Fuller Co., A Gatx Co
General Resource Corp
Guyan Machinery Co
Hanco International Div. of Hannon Electric Co
Heil Process Equipment Co., Div. of Dart Industries, Inc
Herold Mfg. Co
ITT Holub Industries
K.G. Industries, Div. of Carrier Corp
Jeffrey Mining Machinery Div., Dresser Industries Inc
Joy Mfg. Co
Koppers Co., Inc
Lee Supply Co., Inc
Manufacturers Equipment Co., The
New York Blower Co
Peabody ABC
Porter, H.K. Co., Inc
Preiser/Mineco Div., Preiser Scientific Inc
Robinson Industries, Inc
Schauenburg Flexadux Corp
Sprout-Waldron, Koppers Co., Inc
Wayax Industries Ltd
Westinghouse Electric Corp

FEEDERS

1 APRON
2 CHAIN
3 CHEMICAL, CHLORIDE, LIME, REAGENT, ETC.
4 CONTINUOUS-WEIGHING
5 GRIZZLY
6 MINE-CAR HANDLING
7 MINE TRANSFER TO BELT OR CAR
8 OSCILLATING
9 PLATE
10 RECIPROCATING
11 ROTARY
12 SCREW
13 VIBRATING

Aggregates Equipment Inc., (1, 5, 12, 13)
Allis-Chalmers, (13)
Allis-Chalmers, Crushing & Screening Equipment, (5, 13)
Auto Weigh Inc., (1, 3)
Barber-Greene Co., (1, 5, 9, 10, 13)
BIF, a unit of General Signal, (3, 4, 12)
Bonded Scale & Machine Co., (9, 10)
Branford Vibrator Co., The, Div. of Electro Mechanics, Inc., (13)
Calgon Corp., (3)
Campbell Chain Co., (2)
Canton Stoker Corp., (10, 12, 13)
Card Corp., (11)
Carman Industries, Inc., (3, 5, 7, 12, 13)
Carus Chemical Co., (3)
Clarkson Co., (3)
Connellsville Corp., (1, 2, 6, 9, 10, 13)
Crane Co., (3)
Deister Machine Co., Inc., (5, 13)
Dorr Oliver Long, Ltd., (1, 2, 5, 11)
Dover Conveyor & Equipment Co., Inc., (1, 2, 8, 9, 10, 12, 13)
Eriez Magnetics, (5, 13)
ESCO Corp., (11)
FMC Corp., Link-Belt Material Handling Systems Div., (1, 5, 10, 11)

FMC Corp., Material Handling Equipment Div., (3, 4, 5, 13)
Fairfield Engineering Co., (1, 2, 9, 10, 12)
Fairmont Supply Co., (1, 12, 13)
Ferro-Tech, Inc., (3)
Fuller Co., A Gatx Co., (1, 5, 11)
GEC Mechanical Handling Ltd., (1, 5, 9, 11, 12, 13)
Galigher Co., The, (3, 9)
General Kinematics Corp., (5, 8, 13)
General Resource Corp., (11, 12, 13)
Gruendler Crusher & Pulverizer Co., (1, 5, 9, 10, 12)
Hammermills, Inc., Sub of Pettibone Corp., (1, 5, 9, 10, 13)
Hanson, R.A., Co., Ltd
Hewitt-Robins Div., Litton Systems, Inc., (1, 5, 8, 10, 12)
Hoyt & Pettersen, Inc., (6, 10)
Howe Richardson Scale Co., (4)
Industrial Contracting of Fairmont, Inc., (1, 2, 7, 9, 10, 12)
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc., (2)
Info Resometric Scale Inc., (4)
Iowa Manufacturing Co., (1, 5, 10, 13)
Irvin-McKelvy Co., The, (9, 10, 11)
Jones Manufacturing Inc., (1, 2)
Jeffrey Mfg. Div., Dresser Industries Inc., (1, 4, 5, 8, 12, 13)
Jenkins of Retford Ltd., (6)
Joy Mfg. Co., Denver Equipment Div., (3)
KHD Industrieanlagen AG, Humboldt Wedag, (1, 2, 5, 13)
Kanawha Mfg. Co., (1, 6, 10)
Kolberg Mfg. Corp., (9, 10, 13)
Koppers Co., Inc. Metal Products Div., Hardinge Operation
K-Tron Corp., (4, 12, 13)
Lake Shore, Inc., (1)
Lively Mfg. & Equipment Co., (1, 9, 10, 12, 13)
Logan Corp., (1, 2, 5, 8, 10, 12)
Long-Airdox Co. A Div. of the Marmon Group, Inc., (2, 7)
Ludlow-Saylor Wire Cloth, Div. G.S.I.
Manufacturers Equipment Co., The, (1, 2, 9, 10, 11, 12)
Marsh, E. F., Engineering Co., (1, 9, 10)
McLanahan Corp., (5, 9, 10)
McNally Pittsburg Mfg. Corp., (10)
Mineral Services Inc., (4)
Mining Progress, Inc., (2)
Moritz/International, Div. of Barber-Greene, (1, 10)
Nalco Chemical Co., (3)
National Air Vibrator Co., (13)
National Iron Co., (1, 10)
National Mine Service Co.
Nolan Co., The, (6)
Ohmart Corp., (4)
Owens Mfg., Inc., (2, 7)
Pettibone Corp., (1)
Portec, Inc., Pioneer Div., (1, 5, 9, 10, 13)
Preiser/Mineco Div., Preiser Scientific Inc., (4, 13)
Ramsey Engineering, Co., (4)
Read Manufacturing, (12)
Rexnord Inc., (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13)
Rexnord Inc., Process Machinery Div., (1, 5, 13)
Rish Equipment Co., Material Handling Systems Div
Rock Industries Machinery Corp., (1, 2, 5, 9, 10, 13)
Schaffer Poidometer & Machine Co., (4)
Simplicity Engineering, (5, 13)
Solids Flow Control Corp., (13)
Sprout-Waldron, Koppers Co., Inc., (11, 12)
Stamler, W. R., Corp., The, (2, 6, 7)
Stephens-Adamson, (1, 13)
Telsmith Div., Barber-Greene Co., (1, 5, 9, 10, 13)
Thayer Scale Hyer Industries, (4)
Universal Road Machinery Co., (10)
Vibranetics, Inc., (5, 12, 13)
Vibra-Screw Inc., (3, 4, 12, 13)
Wajax Industries Ltd., (5, 13)
Webb, Jervis B., Co., (1, 2, 12, 13)
Webster Mfg. Co., (1, 2, 9, 10)
West Virginia Belt Sales & Repairs Inc., (1, 2, 5, 13)
Willis & Paul Corp., The, (2, 12)
Wilson, R. M., Co., (1, 5, 8, 9, 10, 13)

FILTER CLOTH, MEDIA

American Air Filter Co., Inc.
Ametek
Belleville Wire Cloth Co., Inc.
Durron Co., Inc., The
Envirotech Corp., Eimco BSP Div
GAF Corp
MikroPul Corp
Mine Safety Appliances Co
National Filter Media Corp
Pall Corp
Peabody ABC
Peterson Filters & Engineering Co
Simco Corp
Uniroyal, Inc
Wire Cloth Enterprises, Inc

FILTER MEDIA, METALLIC

Belleville Wire Cloth Co., Inc
CE Tyler Inc
Cleveland Wire Cloth & Mfg. Co
Durron Co., Inc., The
Envirotech Corp., Eimco BSP Div
Ludlow-Saylor Wire Cloth, Div. G.S.I.
Pall Corp
Peterson Filters & Engineering Co
Wire Cloth Enterprises, Inc

FILTERS

1. AIR
2. CENTRIFUGAL
3. DISC, DRUM, VACUUM
4. ENGINE & COMPRESSOR INTAKE
5. FUEL & LUBE OILS
6. HORIZONTAL
7. HYDRAULIC FLUIDS
8. WATER

AMF Inc., (1, 2, 3, 4, 5, 7, 8)
Adams Equipment Co., Inc., (8)
American Air Filter Co., Inc., (1, 2, 4, 6)
Ametek, (2, 3, 6)
BIF, a unit of General Signal, (8)
Bird Machine Co., Inc., (2, 3, 6)
Bowman Distribution, Barnes Group, Inc., (1, 5)
Branford Vibrator Co., The, Div. of Electro Mechanics, Inc., (1)
CE Tyler Inc., (1, 2)
Caterpillar Tractor Co., (1, 4, 5)
Crane Co., (8)
Cummins Engine Co., Inc., (1, 5)
Deran R & D Co., Inc., (8)
Donaldson Co., Inc., (1, 4)
Dorr-Oliver Inc., (3)
Dorr Oliver Long, Ltd., (3)
Dover Conveyor & Equipment Co., Inc., (1)
Durron Co., Inc., The, (6)
Eaton Corp., World Headquarters, (8)
Envirex, Inc., (3)
Federal Supply & Equipment Co., Inc., (7)
Ferro-Tech, Inc., (1, 2)
Fil-I-Vac Corp., (1, 4)
Fleetguard, (4, 7)
Fuller Co., A Gatx Co., (4)
GAF Corp., (5, 7, 8)
Gardner-Denver Co., (1, 4, 5)
General Resource Corp., (1)
Hauck Mfg. Co., (1, 5)
Hayden-Nilos Conflow Ltd., (7, 8)
Heil Process Equipment Co., Div. of Dart Industries, Inc., (1, 2)
Huwood-Irwin Co., (7)
Hydraco, A Unit of General Signal, (7)
Johnson Div., Universal Oil Products, (7, 8)
Johnson-March Corp., The, (1)
Joy Mfg. Co., Denver Equipment Div., (3)
KHD Industrieanlagen AG, Humboldt Wedag, (2, 3)
Lively Mfg. & Equipment Co., (3)
3 M Co., (1)
Matthews, Abe W., Engineering Co., (3)
MikroPul Corp
Mine Safety Appliances Co., (1)
Mining Machine Parts, Inc., (5, 7)
Monitor Mfg. Co., (4)
Morgantown Machine & Hydraulics, Inc., Div. Nat'l Mine Service Co., (8)
National Environmental Inst. Inc., (1)
Norton Co., (8)
Pall Corp., (1, 4, 5, 7, 8)
Peterson Filters & Engineering Co., (3)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 8)
Redding Co., James A., (3)
Research-Cottrell, Inc., (1, 2)
Sala International, (3)
Schroeder Bros. Corp., (7)
Scott Aviation, A Div. of A-T-O, Inc., (1)
Sly, W. W., Mfg. Co., (1)
Sperry Vickers Div., Sperry Rand Corp., (7)
Spraying Systems Co., (8)
Sprout Waldron, Koppers Co., Inc., (1)
Stanadyne/Hartford Div., (5)
Streamline Filters Inc., (3, 6)
Thor Power Tool Co., (1)
Thurman Scale Co. Div. Thurman Mfg. Co., (1)
Unifloc Limited
Union Carbide Corp., (1)
Union Oil Co. of California, (5)
Varian Associates
WABCO Fluid Power Div., an American Standard Co., (1)
Weatherhead Co., The, (2, 5, 7)
Western Precipitation Div., Joy Mfg. Co., (1)
Wheelabrator-Frye Inc., Air Pollution Control Div., (1)
Wiggins Connectors Div. Delaval Turbine Inc., (5)
Willson Products Div., ESB, Inc.
Wilson, R. M., Co., (1)
Wire Cloth Enterprises, Inc., (1)
Workman Developments, Inc., (3)

FINANCIAL SERVICES

Bache & Co., Inc
Capital Conservation Group
CIT Corp
Citizens Fidelity Bank & Trust Co
Dean Witter & Co., Inc
Firstmark Morrison Inc
First National Bank of Maryland, Energy Resources Div
Manufacturers Hanover Leasing Corp

FIRE ALARMS, DETECTORS

Adams Equipment Co., Inc
Air Lert, Inc
A T O Inc
Conrac Corp
Fire Protection Supplies Inc
Hayden Nilos Conflow Ltd
Jabco, Inc
Kidde, Walter, & Co., Belleville Div
Mine Safety Appliances Co
National Mine Service Co
Norris Industries, Fire & Safety Equipment Div
Preiser/Mineco Div., Preiser Scientific Inc
Pyott-Boone, Inc
Red Comet, Inc
Schroeder Bros. Corp
Tensio-Wire Fire Systems, Inc
West Virginia Belt Sales & Repairs Inc
Wilson, R. M., Co

FIRE EXTINGUISHERS

1. CHEMICALS, FLUIDS
2. FLUID
3. CO2, DRY CHEMICAL

Ansul Co., The, (3)
A-T-O Inc., (1, 2, 3)
Big Sandy Electric & Supply Co., Inc., (1, 3)
Bowman Distribution, Barnes Group, Inc., (3)
du Pont de Nemours, E. I. & Co. Inc., (1)
Fairmont Supply Co., (1, 3)
Fire Protection Supplies Inc., (3)
Hayden-Nilos Conflow Ltd., (1, 2, 3)
Kidde, Walter, & Co., Belleville Div., (2, 3)
Logan Corp., (3)
3 M Co., (1)
Marathon Coal Bit Co., Inc., (3)
Michael Walters Ind., (3)
National Foam System Inc
National Mine Service Co., (1, 3)
Norris Industries, Fire & Safety Equipment Div
Preiser/Mineco Div., Preiser Scientific Inc., (1)
Red Comet, Inc., (1, 2, 3)

FIRE-PROTECTION SYSTEMS

Ansul Co., The
A T O Inc
Austin, J. P., Inc
Automatic Sprinkler Corp
Big Sandy Electric & Supply Co., Inc
Cementation Mining Ltd
Fiberglass Resources Corp
Fire Protection Supplies Inc
Hayden Nilos Conflow Ltd
Huwood Irwin Co

Jabco, Inc
Kidde, Walter, & Co., Belleville Div
Lee Supply Co., Inc
3 M Co
Michael Walters Ind
Mine Safety Appliances Co
National Foam System Inc
National Mine Service Co
Norris Industries, Fire & Safety Equipment Div
Perungers Inc
Preiser/Mineco Div., Preiser Scientific Inc
Pyott Boone, Inc
Red Comet, Inc
S & S Machinery Sales, Inc
Schroeder Bros. Corp
Twisto Wire Fire Systems, Inc
Uniroyal, Inc
West Virginia Belt Sales & Repairs Inc
Wilson, R. M., Co

FLIGHTS, CONVEYOR-LINE

Acco Mining Sales Div
Campbell Chain Co
Cincinnati Mine Machinery Co
Duquesne Mine Supply Co
ESCO Corp
Fairmont Supply Co
Holz Rubber Co., A Rendron Div
Howard-Irwin Co
Jeffrey Mining Machinery Div., Dresser Industries Inc
Kanawha Mfg. Co
Laubenstein Mfg. Co
Long-Airdox Co., A Div. of the Marmon Group, Inc
Mining Machine Parts, Inc
National Mine Service Co
Rexnord Inc
Stamler, W. R., Corp., The
Webb, Jervis B., Co
West Virginia Belt Sales & Repairs Inc
Wilmot Engineering Co
Wilson, R. M., Co
Workman Developments, Inc

FLOAT & SINK TEST SOLUTIONS

American Minechem Corp
Preiser/Mineco Div., Preiser Scientific Inc

FLOAT AND SINK TESTERS

Preiser/Mineco Div., Preiser Scientific Inc

FLOCCULATING AGENTS

Allied Chemical Corp., Industrial Chemicals Div
American Cyanamid Co., Industrial Chemicals & Plastics Div
American Minechem Corp
Ashland Chemical Co
Betz Laboratories
Calgon Corp
Carus Chemical Co
Dowell Div. of the Dow Chemical Co
du Pont de Nemours, E. I. & Co Inc
Goodrich, B. F., Chemical Co
Hercules Inc
Hubinger Co., The
Nalco Chemical Co
Preiser/Mineco Div., Preiser Scientific Inc
Unifloc Limited

FLOTATION CONDITIONERS, FROTHERS, REAGENTS

Alcolac Inc
American Cyanamid Co., Industrial Chemicals & Plastics Div
American Minechem Corp
Ashland Chemical Co
Betz Laboratories
Calgon Corp
Celanese Chemical Co
Deneen Company, The
Dowell Div. of the Dow Chemical Co
Hercules Inc
Joy Mfg. Co., Denver Equipment Div
KHD Industrieanlagen AG, Humboldt Wedag
PPG Industries, Inc., Chemical Div
Preiser/Mineco Div., Preiser Scientific Inc
Shell Chemical Co., Chemical Sales
Unifloc Limited
Union Carbide Corp
Wemco Engineering Co

FLOTATION CELLS, MACHINERY PLANTS

Deneen Company, The
Galigher Co., The
GEOMIN
Heyl & Patterson, Inc
Joy Mfg. Co., Denver Equipment Div
KHD Industrieanlagen AG, Humboldt Wedag
Lively Mfg. & Equipment Co
Sala International
Sala Machine Works Ltd
Unifloc Limited
Uniroyal, Inc
WEMCO Div., Envirotech Corp
West Virginia Belt Sales & Repairs Inc

FLOTATION TESTING

Commercial Testing & Engineering Co
Deneen Company, The
Dowell Div. of the Dow Chemical Co
Galigher Co., The
GEOMIN
Hazen Research, Inc
Heyl & Patterson, Inc
Joy Mfg. Co., Denver Equipment Div
KHD Industrieanlagen AG, Humboldt Wedag
Preiser/Mineco Div., Preiser Scientific Inc
Sala International
Unifloc Limited
WEMCO Div., Envirotech Corp

FLOW METERS

Acco, Bristol Div
American Meter Div., Singer Co., The
Babcock & Wilcox
BIF, a unit of General Signal
Calgon Corp
Capital Controls Co
Federal Supply & Equipment Co., Inc
Foxboro Co., The
General Electric Co., Instrument Products Operation
Halliburton Services Research Center
Hayden Nilos Conflow Ltd
Honeywell Inc., Process Control Div
J-Tec Associates, Inc
Kay-Ray Inc
Leeds & Northrup Co
Modern Engineering Co
National Environmental Inst. Inc
Pace Transducer Co., Div. of C. J. Enterprises
Preiser/Mineco Div., Preiser Scientific Inc
Stevens, Inc., C. W.
Taylor Instrument Process Control Div., Sybron Corp
Union Carbide Corp
Unique Products Co
Viking Oil & Machinery Co
WESMAR Level Monitor Div
Westinghouse Electric Corp

FLUID-POWER COMPONENTS

Abex Corp., Denison Div
Aeroquip Corp
Anixter Mine & Smelter Supply
Arc Corp., The
A T O Inc
Dynex Div., Applied Power Inc
ENERPAC, Div. of Applied Power Inc
Guyan Machinery Co
Houghton & Co., E. F.
Imperial Eastman Corp
Lucas Industries, Fluid Power Div
National Supply Co., Div. of Armco Steel Corp
Owatonna Tool Co
Rexnord Inc
Sperry Vickers Div., Sperry Rand Corp
Twin Disc, Inc
Weatherhead Co., The

FREEZEPROOFING CHEMICALS

Allied Chemical Corp., Industrial Chemicals Div
Celanese Chemical Co
Dowell Div. of the Dow Chemical Co
Hardy Salt Co
International Salt Co
Morton Salt Co
Preiser/Mineco Div., Preiser Scientific Inc
Viking Oil & Machinery Co

FURNACES

1 COAL-DRYING
2 CONSTRUCTION AND PARTS
3 HEAT-TREATING
4 LABORATORY
5 METAL-MELTING
6 PLANT-HEATING

Bigelow-Liptak Corp., (1, 2)
Campbell, E. K., Co., (6)
Commercial Testing & Engineering Co., (4)
Dravo Corp., (1, 6)
Heyl & Patterson, Inc., (1)
K-G Industries, Inc., (1)
KHD Industrieanlagen AG, Humboldt Wedag, (1, 2, 3, 5, 6)
Leco Corp., (4)
Leeds & Northrup Co., (3)
Mine & Smelter Industries, (3, 4, 5)
Preiser/Mineco Div., Preiser Scientific Inc., (4)
Soiltest, Inc., (4)
Varian Associates, (3, 4)
Wall Colmonoy, (3)
Whiting Corp., (3, 5)
Williams Patent Crusher & Pulv. Co., (1)

GAGES, LIQUID-LEVEL

Alemite & Instrument Div., Stewart Warner Corp
Babcock & Wilcox
Bindicator Co., Div. of Improvecon Corp
Crane Co
Foxboro Co., The
Honeywell Inc., Process Control Div
Kay-Ray Inc
Lunkenheimer Co., Div. of Conval Corp., Sub. of Condec Corp
Ohmart Corp
Preiser/Mineco Div., Preiser Scientific Inc
Stevens, Inc., C. W.
Texas Nuclear
Unique Products Co
WESMAR Level Monitor Div
Westinghouse Electric Corp

GAGES, PRESSURE, VACUUM, FLOW

Acco, Helicoid Gage Div
Adams Equipment Co., Inc
Alemite & Instrument Div., Stewart Warner Corp
American Meter Div., Singer Co., The
Anixter Mine & Smelter Supply
Beckman Instruments, Inc
Duriron Co., Inc., The
ENERPAC, Div. of Applied Power Inc
Foxboro Co., The
Hayden Nilos Conflow Ltd
Honeywell Inc., Process Control Div
Minnesota Automotive Inc
Modern Engineering Co
Pace Transducer Co., Div. of C. J. Enterprises
Preiser/Mineco Div., Preiser Scientific Inc
Schroeder Bros. Corp
Snap On Tools Corp
Templeton, Kenly & Co
TOTCO Div., Baker Oil Tools, Inc
Westinghouse Electric Corp

GAS DETECTORS, MINE

American Minechem Corp
A T O Inc
Bacharach Instrument Co., Mining Div
Bullard, E. D., Co
CSE Mine Service Co
du Pont de Nemours, E. I. & Co Inc
Edmont Wilson, Div. of Becton, Dickinson & Co
Fire Protection Supplies Inc

Mine Gas Monitors, Inc
Mine Safety Appliances Co
National Environmental Inst Inc
National Mine Service Co
Preiser/Mineco Div., Preiser Scientific Inc
Scott Aviation, A Div. of A-T-O, Inc
Wilson, R. M., Co

GRIZZLIES

(SEE FEEDERS, GRIZZLY)

HAULAGES, R.R. CAR, BARGE, BOAT

ACF Industries, Inc
Heyl & Patterson, Inc
Interstate Equipment Corp.
McDowell-Wellman Engrg. Co

HEAVY-MEDIUM RECLAMATION EQUIPMENT

(SEE MAGNETITE, RECOVERY SEPARATORS)

HEAVY-MEDIUM SEPARATORS

(SEE WASHERS, HEAVY-MEDIUM)

HOPPER OUTLETS-NONPLUGGING

Kalenborn
Solids Flow Control Corp
Webb, Jervis B., Co

HOPPERS

Aggregates Equipment Inc
Bethlehem Steel Corp
Bonded Scale & Machine Co
Concrete Equipment Co., Inc
DEMAG Lauchhammer
Dorr Oliver Long, Ltd
Dover Conveyor & Equipment Co., Inc
Easton Car & Construction Co
Enterprise Fabricators, Inc
Fairfield Engineering Co
Ferro-Tech Inc
General Resource Corp
Hammermills, Inc., Sub of Pettibone Corp
Hanson, R.A., Disc., Ltd
Industrial Contracting of Fairmont, Inc
Lively Mfg. & Equipment Co
Marsh, E. F., Engineering Co
McNally Pittsburg Mfg. Corp
Rish Equipment Co., Material Handling Systems Div
Rock Industries Machinery Corp
Somerset Welding & Steel Inc
Sprout Waldron, Koppers Co., Inc
United McGill Corp
Vibra-Screw Inc
Webster Mfg. Co
West Virginia Belt Sales & Repairs Inc
Wilks & Paul Corp., The
Wilmot Engineering Co
Wilson, R. M., Co

HOPPERS, WEIGH

Bethlehem Steel Corp
Concrete Equipment Co., Inc
Connellsville Corp
Easton Car & Construction Co
Fairbanks Weighing Div., Colt Industries
Fairfield Engineering Co
General Resource Corp
Howe Richardson Scale Co
Railweight, Inc
Sprout-Waldron, Koppers Co., Inc
Thayer Scale Hyer Industries
Vibra-Screw Inc
Webb, Jervis B., Co

HYDROCYCLONES

(SEE WASHERS, COAL, CYCLONE WATER)

HYDROSEPARATORS

(SEE WASHERS, COAL)

INSTRUMENTS, RECORDING, PRESSURE, TEMPERATURE, ETC

Acco, Bristol Div
Adams Equipment Co., Inc
Alemite & Instrument Div., Stewart Warner Corp
American Meter Div., Singer Co., The
Analytical Measurements, Inc
A-T-O Inc
Babcock & Wilcox
Bacharach Instrument Co., Mining Div
Barnes Engineering Co
Beckman Instruments, Inc
Biddle Co., James G
Capital Controls Co
Fisher Controls Co
Foxboro Co., The
General Electric Co., Industrial Sales Div
General Electric Co., Instrument Products Operation
Hayden Nilos Conflow Ltd
Honeywell Inc., Process Control Div
J-Tec Associates, Inc
Leeds & Northrup Co
Martindale Electric Co
Measurement & Control Systems Div., Gulton Industries Inc
National Environmental Inst Inc
Pace Transducer Co., Div. of C. J. Enterprises
Preiser/Mineco Div., Preiser Scientific Inc
Pyott Boone, Inc
Quest Electronics
Revere Corp. of America, Sub. of Neptune Intl Corp
Sortex Co. of North America, Inc
Taylor Instrument Process Control Div., Sybron Corp
TOTCO Div. Baker Oil Tools, Inc
Walter Nold Co
Westinghouse Electric Corp
Wilson, R. M., Co

INSURANCE, CASUALTY, WORKMEN'S COMPENSATION

Flat Top Insurance Co
Old Republic Insurance Co

INSURANCE, PLANT & EQUIPMENT

Bellefonte Insurance Cos., Sub. of Armco Steel Corp
Flat Top Insurance Co

JIGS

(SEE WASHERS, JIG)

LABORATORY EQUIPMENT

Ainor Instrument Co
Analytical Measurements, Inc
Anixter Mine & Smelter Supply
A-T-O Inc
Bacharach Instrument Co., Mining Div
Bausch & Lomb, SOPD Div
Beckman Instruments, Inc
CE Tyler Inc
Commercial Testing & Engineering Co
Davis Instrument Mfg. Co
Dunron Co., Inc., The
Fisher Scientific Co
Galigher Co., The
General Electric Co., Instrument Products Operation
General Scientific Equipment Co
GenRad
Gilson Screen Co
Hacker Instruments Inc
Joy Mfg. Co., Denver Equipment Div
KHD Industrieanlagen AG, Humboldt Wedag
K-Tron Corp
Leco Corp
Mineral Services Inc
Morse Bros. Machinery Co
Norton Co
Numonics Corp
Perkin-Elmer Corp
Preiser/Mineco Div., Preiser Scientific Inc
Quest Electronics
Sala International
Soiltest, Inc
Spoehrman Co
Westinghouse Electric Corp

LABORATORY TESTING

Anixter Mine & Smelter Supply
Barnes & Reinecke, Inc
Beckman Instruments, Inc
Commercial Testing & Engineering Co
Davis Instrument Mfg. Co
Fisher Scientific Co.
Galigher Co., The
General Resource Corp
GEOMIN
Hazen Research, Inc
K-Tron Corp
McDowell-Wellman Engrg. Co
Mineral Services Inc
NUS Corp., Robinson & Robinson Div
Preiser/Mineco Div., Preiser Scientific Inc
Sala International
Stearns Magnetics Inc., Div. of Magnetics Intl

LEVEL MEASUREMENT & CONTROLS

Acco, Bristol Div
Automation Products, Inc
BIF, a unit of General Signal
Big Noise Instruments, Div. of Improvecon Corp
Bindicator Co., Div. of Improvecon Corp
Communication & Control Eng. Co. Ltd
DeBvan Electronics, Inc
Fisher Controls Co
Foxboro Co., The
Fuller Co., A Gatx Co
General Electric Co., Industrial Sales Div
Great Lakes Instruments, Inc
Honeywell Inc., Process Control Div
Kay Ray Inc
Leeds & Northrup Co
Lee Supply Co., Inc
Metritape Inc
Micro Switch, A Div. of Honeywell
Mineral Services Inc
Monitor Mfg. Co
Monitrol Mfg. Co
Pace Transducer Co., Div. of C. J. Enterprises
Preiser/Mineco Div., Preiser Scientific Inc
Quest Electronics
Ramsey Engineering Co
Stevens Inc., C. W
Taylor Instrument Process Control Div., Sybron Corp
Texas Nuclear
Unique Products Co
WESMAR Level Monitor Div
Westinghouse Electric Corp

LINING

1 CHUTE, FLUME & TANK CERAMIC, GLASS
2 CHUTE & FLUME - METAL
3 CHUTE, FLUME & TANK - RUBBER
4 CONCRETE
5 CYCLONE
6 FURNACE
7 HYDRAULIC PUMP
8 SHEET, CONCRETE, STEEL
9 SPRAYABLE PLASTIC
10 PLASTIC

A S H Pump, Div. of Envirotech Corp. (3)
Adhesive Engineering Co. (9)
Aeroquip Corp. (3)
American Alloy Steel, Inc. (2, 8)
Amsco Div., Abex Corp. (2, 7)
Automatic Vulcanizers Corp. (3)
Babcock & Wilcox (6)

Bigelow Liptak Corp., (5, 6)
Bonded Scale & Machine Co., (3)
Boston Industrial Products Div., American Biltrite Inc., (3)
Challenge Cook Bros., Inc., (4)
Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp., (3)
Contractors Warehouse Inc., (4)
Corhart Refractories Co., Div. of Corning Glass Works, (1, 6)
Detrick, M. H., Co., (1, 6)
Dosco Corp., (8)
Durex Products, Inc., Natl Wire Cloth Div., (3, 10)
Equipment Mfg. Services, Inc., (7)
ESCO Corp., (3)
Fairmont Supply Co., (1, 3, 4, 5, 7, 9)
Galigher Co., The, (3)
Gates Rubber Co., The, (3, 9)
General Refractories Co., U.S. Refractories Div., (6)
Goodall Rubber Co., (3)
Goodrich, B. F. Engineered Systems Co., (3)
Goodyear Tire & Rubber Co., (3, 9)
Greenbank Cast Basalt Eng. Co. Ltd., (1, 5)
Greengate Industrial Polymers Ltd., (3)
Griffolyn Co., Inc., (10)
Guyan Machinery Co., (3, 5, 7, 9)
Hanson, R.A., Disc., Ltd.
Hardman Inc., (3, 9)
Heil Process Equipment Co., Div. of Dart Industries, Inc., (1, 3, 9)
Hintz Rubber Co., A Randren Div., (3, 5)
Hiwood Irwin Co., (7)
Industrial Contracting of Fairmont, Inc., (2)
Irathane Systems, Inc., (9)
Jones Manufacturing Inc., (2)
Kalenborn
Kanawha Mfg. Co., (2)
Laubenstein Mfg. Co., (2)
Lee Supply Co., Inc., (1)
Linatex Corp. of America, (3)
3 M Co., (1)
North State Pyrophyllite Co., Inc., (6)
Norton Co., (6)
Plastic Techniques, Inc., (10)
Plibrico Company, (5, 6)
Poly Hi, Inc., (3, 5, 7, 8, 10)
Preiser/Mineco Div., Preiser Scientific Inc., (3, 9)
Raychem Corp., (10)
Redding Co., James A., (1, 4, 5)
Republic Steel Corp., (8)
Stonhard, Inc., (1, 4, 5, 7, 8, 9)
Thomas Foundries Inc., (2)
Trelleborg Rubber Co., Inc., (3)
Uniroyal, Inc., (3)
U.S. Polymers, Sub. of Armco Steel Corp., (10)
Universal Road Machinery Co., (2, 3)
Wajax Industries Ltd., (3)
West Virginia Belt Sales & Repairs Inc., (1, 3, 5)
Wilson, R. M., Co., (1, 3, 10)
Workman Developments, Inc., (1, 3, 10)

LOADERS, PORTABLE & SELF-PROPELLED, BELT, BUCKET

Aggregates Equipment Inc.
Athey Products Corp.
DEMAG Lauchhammer
Eaton Corp., Forestry & Construction Equipment Div.
Fairfield Engineering Co.
Hanson, R.A., Disc., Ltd.
Marsh, E. F., Engineering Co.
Mracher Mfg. Co. Inc.
Mining Equipment Mfg. Corp.
North American O&K
Tiger Equipment & Services, Ltd./O & K Mining Equipment
Wagner Mining Equip.
Wajax Industries Ltd.

LOADING BOOMS

1. APRON
2. BELT
3. CHAIN

Dico Co., Inc., (1)
Dover Conveyor & Equipment Co., Inc., (2, 3)
ELMAC Corp., (2)
FMC Corp., Link-Belt Material Handling Systems Div., (2)
Fairfield Engineering Co., (1, 2, 3)
GEC Mechanical Handling Ltd., (1, 2)
Hanson, R.A., Disc., Ltd.
Heyl & Patterson, Inc., (2)
Industrial Contracting of Fairmont, Inc.
Jeffrey Mfg. Div., Dresser Industries Inc., (1, 2)
Jenkins of Retford Ltd., (2)
Lively Mfg. & Equipment Co., (1, 2, 3)
McNally Pittsburg Mfg. Corp., (1, 2)
Rexnord Inc., (1, 2, 3)
Savage, W. J., Co., (2)
Stephens-Adamson, (2)
Unifloc Limited
Webb, Jervis B., Co., (2, 3)
Willis & Paul Corp., The, (2, 3)
Wilson, R. M., Co., (2)

LOADING EQUIPMENT, AUTOMATIC, R.R. & TRUCK

American Poclain Corp.
Fairfield Engineering Co.
Fesco International, Inc.
Fuller Co., A Gatx Co.
General Resource Corp.
Hanson, R.A., Disc., Ltd.
Jenkins of Retford Ltd.
Lively Mfg. & Equipment Co.
Mathews, Abe W., Engineering Co.
McDowell-Wellman Engrg. Co.
McNally Pittsburg Mfg. Corp.
Nolan Co., The
Rexnord Inc.
Webb, Jervis B., Co.

LUBRICATING SYSTEMS

1. CENTRALIZED, CONTINUOUS
2. MANUAL
3. SPRAY, OIL MIST

Adams Equipment Co., Inc.
Aeroquip Corp., (2)
Alemite & Instrument Div., Stewart Warner Corp., (1, 2, 3)
Aro Corp., The, (2)
CSE Mine Service Co., (2)
Cypher Co., The, (1, 2)
Dravo Corp., (1, 3)
Duff-Norton Co., (3)
Eaton Corp., World Headquarters, (1, 2, 3)
Eaton Corp., Industrial Drives Div., (1, 2, 3)
E Power Industries Corp., (1, 2, 3)
Fairmont Supply Co., (1, 2, 3)
Gardner-Denver Co., (1, 2)
Iowa Mold Tooling Co., Inc.
Keystone Div., Pennwalt Corp., (2)
Lincoln St. Louis Div. of McNeil Corp., (1, 2, 3)
Portadrill, Div. of Smith International Inc., (3)
Spraying Systems Co.
Trabon Lubricating Systems, Div. of Houdaille Industries, Inc., (1, 2, 3)
Trico Mfg. Corp., (1, 2, 3)
Wheelabrator-Frye, Inc., Materials Cleaning Systems, (2)
Wiggins Connectors Div., Delaval Turbine Inc.

LUBRICATORS

1. WHEEL, FLANGE
2. JOURNAL BEARING
3. RAIL

Abex Corp., Railroad Products Group, (3)
CSE Mine Service Co., (1, 2)
Eaton Corp., Industrial Drives Div.
E Power Industries Corp.
Lincoln St. Louis Div. of McNeil Corp., (1)
Lunkenheimer Co., Div. of Conval Corp., Sub. of Condec Corp.
Trico Mfg. Corp., (2)

MAGNETITE

Foote Mineral Co.
Hillcrest Co., Mt. Hope Mine Div.
Mineral Services Inc.
Rosa Viking Corp., Div. C. Rosa Coal Co.
Viking Oil & Machinery Co.

MAGNETITE METERS

MAGNETITE, RECOVERY SEPARATORS

Dings Co., Magnetic Group
Eriez Magnetics
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc.
Mineral Services Inc.
Sala Machine Works Ltd.
Stearns Magnetics Inc., Div. of Magnetics Intl.
Unifloc Limited
Wilson, R. M., Co.

MAGNETS

1. CHUTE & PLATE TYPES
2. DRUM & PULLEY TYPES
3. SUSPENDED

Colt Industries, Crucible, (1)
Dings Co., Magnetic Group, (1, 2, 3)
Duplex Mill & Mfg. Co., (1)
Eriez Magnetics, (1, 2, 3)
3 M Co.
Mineral Services Inc., (1, 2, 3)
National Electric Coil Div. of McGraw Edison Co., (3)
Savage, W. J. Co., (1)
Square D Co., (1)
Stearns Magnetics Inc., Div. of Magnetics Intl., (1, 2, 3)
Varian Associates
Wilson, R. M., Co., (1, 2, 3)

MAPS, TOPOGRAPHIC, PHOTOGRAPHIC

Aerial Surveys, Inc.
Aero Service Div., Western Geophysical Co. of Amer.

Berger Associates, Ltd.
GEOMIN

MINE DRAINAGE CONTROL SYSTEMS

(SEE POLLUTION CONTROL SYSTEMS)

MOISTURE INDICATORS, METERS, TESTERS

Acco, Bristol Div.
Bacharach Instrument Co., Mining Div.
Beckman Instruments, Inc.
Concrete Equipment Co., Inc.
du Pont de Nemours, E. I. & Co. Inc.
Foxboro Co., The
Kay Ray Inc.
Preiser/Mineco Div., Preiser Scientific Inc.
Soiltest, Inc.

MOTOR REWINDING, REPAIR

Atkinson Armature Works
Everson Electric Co.
FMC Corp., Mining Equipment Div.
Flood City Brass & Electric Co.
General Electric Co., Industrial Sales Div.
Guyan Machinery Co.
Hanco International Div. of Hannon Electric Co.
Joy Mfg. Co.
Joy Service Center, Div. Joy Mfg. Co.
Louis Allis Div., Litton Industrial Products, Inc.
National Electric Coil Div. of McGraw-Edison Co.
Pennsylvania Electric Coil, Inc.
Reliance Electric Co.
S & S Machinery Sales, Inc.
West Virginia Armature Co.
Westinghouse Electric Corp.

MOTORS

1. AC

2. AIR
3. DC
4. FLUID, HYDRAULIC
GEAR-(SEE GEARMOTORS)

Abex Corp., Denison Div., (4)
Acme Machinery Co., (2)
Adams Equipment Co., Inc., (1)
Allis Chalmers, (1, 3)
American Poclain Corp., (4)
Anixter Mine & Smelter Supply, (1, 2, 3, 4)
Aro Corp., The, (2)
ASEA Inc., (1, 3)
Big Sandy Electric & Supply Co., Inc
Browning Mfg. Div., Emerson Electric Co., (1, 3)
Chicago Pneumatic Equipment Co., (2)
Commercial Shearing, Inc., (4)
Compton Electrical Equipment Corp., (1, 2)
Conrac Corp., (1, 3)
Continental Conveyor & Equipment Co., (1)
Delavan Mfg. Co., (4)
Dover Conveyor & Equipment Co., Inc., (1, 3)
Dynex Div., Applied Power Inc., (4)
Eaton Corp., World Headquarters, (1, 3, 4)
Eaton Corp., Industrial Drives Div., (1, 3)
Eimco Mining Machinery, Envirotech Corp., (2)
Electric Machinery Mfg. Co., (1)
Electric Products Div., Portec Inc., (1)
FMC Corp., Mining Equipment Div., (1, 3)
Fairmont Supply Co., (1, 3)
Fenner, J. H. & Co., Ltd., (1, 2, 3)
Fidelity Electric Co. Inc., (3)
Gardner-Denver Co., (2)
General Electric Co., DC Motor & Generator Dept., (3)
General Electric Co., Industrial Sales Div., (1, 3)
Gould Inc., Century Electric Div., (1, 3)
Harnischfeger Corp
Hydraulic Products Inc., (4)
Hydreco, A Unit of General Signal, (4)
Ingersoll-Rand Co., (2)
Jeffrey Mining Machinery Div., Dresser Industries Inc., (1)
Joy Mfg. Co., (2)
Joy Service Center, Div. Joy Mfg. Co., (1, 3, 4)
Kersey Mfg. Co., (3)
Lawnel Corp., (3)
Lee Supply Co., Inc., (1, 2, 3)
Lima Electric Co., Inc., (1)
Lincoln Electric Co., The
Lincoln St. Louis Div. of McNeil Corp., (2)
Logan Corp., (1, 3)
Louis Allis Div., Litton Industrial Products, Inc., (1, 3)
Lucas Industries, Fluid Power Div., (4)
Micro Switch, A Div. of Honeywell, (3)
Mining Progress, Inc., (1, 2, 4)
Morse Chain, Div. of Borg-Warner Corp., (1, 3)
Mosebach Manufacturing Co
National Mine Service Co., (1, 2)
North American Hydraulics, Inc., (4)
Pennsylvania Electric Coil, Inc., (1, 3)
Porter, H.K. Co., Inc., (1, 2, 3)
Prestolite Electrical Div. of Eltra Corp., (1, 3)
Reliance Electric Co., (1, 3)
Rexnord Inc., (4)
Robicon Corp., (1, 3)
Sperry Vickers Div., Sperry Rand Corp., (4)
Sterling Power Systems, Inc., A Sub. of The Lionel Corp., (1)
Thor Power Tool Co., (2)
U. S. Electrical Motors Div. Emerson Electric Co., (1, 3)
West Virginia Armature Co., (1, 3, 4)
Westinghouse Electric Corp., (1, 3)
Wilson, R. M., Co., (1, 2, 3, 4)

NOZZLES, FOG

A-T-O Inc
Bete Fog Nozzle, Inc
Delavan Mfg. Co
FMC Corp., Agricultural Machinery Div
Fire Protection Supplies Inc
Goodall Rubber Co
Hahn Industries, Mine & Mill Specialties
Industrial Rubber Products Co
Mining Progress, Inc
National Mine Service Co
Preiser/Mineco Div., Preiser Scientific Inc
Sonic Development Corp
Spraying Systems Co
Viking Oil & Machinery Co
Workman Developments, Inc

NOZZLES, SPRAY

Acco Mining Sales Div
Adams Equipment Co., Inc
Aro Corp., The
A-T-O Inc
Bete Fog Nozzle, Inc
Big Sandy Electric & Supply Co., Inc
Bowman Distribution, Barnes Group, Inc
Dexter Concentrator Co. Inc., The
Delavan Mfg. Co
FMC Corp., Agricultural Machinery Div
Fairmont Supply Co
Fire Protection Supplies Inc
General Electric Co., Carboloy Systems Dept
Goodall Rubber Co
Hahn Industries, Mine & Mill Specialties
Hayden Nilos Conflow Ltd
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc
Industrial Rubber Products Co
Johnson March Corp., The
Krebs Engineers
Lee Supply Co., Inc
Lincoln St. Louis Div. of McNeil Corp
Logan Corp
Mining Progress, Inc
National Mine Service Co
Preiser/Mineco Div., Preiser Scientific Inc
Rexnord Inc
Sonic Development Corp
Spraying Systems Co
Uniroyal, Inc
Viking Oil & Machinery Co
Workman Developments, Inc

NOZZLES, WET ROCK DUSTING

Bete Fog Nozzle, Inc
Delavan Mfg. Co
General Electric Co., Carboloy Systems Dept
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc
Norton Co
Sonic Development Corp
Spraying Systems Co
Workman Developments, Inc

PANELS & PANELBOARDS, INSTRUMENTS, CONTROL

Acco, Electro-Mech Div
Aggregates Equipment Inc
Allen-Bradley Co
Anixter Mine & Smelter Supply
Bacharach Instrument Co., Mining Div
Beckman Instruments, Inc
Cam-Lok Div., Empire Products, Inc
Communication & Control Eng. Co. Ltd
Compton Electrical Equipment Corp
Concrete Equipment Co., Inc
Crouse Hinds Co
Cutler Hammer, Inc
Fairfield Engineering Co
Fairmont Supply Co
Foxboro Co., The
GTE Sylvania Inc
General Electric Co., Industrial Sales Div
General Resource Corp
Guyan Machinery Co
Hanco International Div. of Hannon Electric Co
HB Electrical Mfg. Co
Honeywell Inc., Process Control Div
I T E Imperial Corp
Leeds & Northrup Co
Louis Allis Div., Litton Industrial Products, Inc
Preiser/Mineco Div., Preiser Scientific Inc
Pyott Boone, Inc
Seton Name Plate Corp
Square D Co
TOTCO Div. Baker Oil Tools, Inc
Webb, Jervis B. Co
Westinghouse Electric Corp

PH INDICATORS, RECORDERS

Acco, Bristol Div
Analytical Measurements, Inc
Babcock & Wilcox
Beckman Instruments, Inc
Betz Laboratories
CSE Mine Service Co
Electrofact
Fisher Scientific Co
Foxboro Co., The
Great Lakes Instruments, Inc
Leeds & Northrup Co
Perkin-Elmer Corp
Preiser/Mineco Div., Preiser Scientific Inc
Soiltest, Inc

PIPE

1. ALUMINUM
2. ALUMINUM PLASTIC
3. ALUMINUM, STEAM TRACED
4. ASBESTOS-CEMENT
5. BRONZE, COPPER, RED BRASS
6. CAST IRON, WROUGHT IRON
7. LINED
8. CORROSION RESISTANT
9. CORRUGATED
10. DRIVE & DRIVING WINCHES
11. PLASTIC
12. RUBBER
13. RUBBER-LINED
14. SEAMLESS
15. SPIRAL WELDED
16. STAINLESS STEEL
17. STEEL, STEEL WELDED
18. STEEL, PLASTIC-COATED
19. WOOD, WOOD-STAVE
20. GLASS FIBER REINFORCED

Acker Drill Co., Inc., (10)
Alcoa, (1, 3, 14)
Allegheny Ludlum Steel Corp., (8, 14, 16, 17)
Ampco Metal Div., Ampco-Pittsburgh Corp., (5, 8)
Anixter Mine & Smelter Supply, (8, 11, 20)
Armco Steel Corp., Product Info., (7, 8, 9, 11, 14, 16)
Babcock & Wilcox, (8, 14, 16, 17)
Bethlehem Steel Corp., (9, 14, 17, 18)
C F & I Steel Corp., (14)
Carlon Co., (11)
Capital City Industrial Supply Co
Certain-Teed Products Corp., Pipe & Plastics Group, (4, 11)
CIBA GEIGY Corp., Pipe Systems Dept., (8, 20)
Cincinnati Rubber Mfg. Co., Div. of Stewart Warner Corp., (12)
Colt Industries, Crucible, (8, 16)
Continental Rubber Works, Sub. of Continental Copper & Steel Industries, Inc., (12)
Contractors Warehouse Inc., (15, 17)
Deitrich, M. H., Co., (7, 8)
du Pont de Nemours, E. I. & Co. Inc., (11)
Duriron Co., Inc., The, (8)
ESCO Corp., (6, 8, 16)
Fairmont Supply Co., (11, 12, 13, 14, 15, 20)
Federal Mogul Corp., (11)
Fiberglass Resources Corp., (8, 11)
Flexible Valve Corp., (12)
Foster, L. B. Co., (6, 7, 14, 15, 17)
Galigher Co., The, (7, 8, 13)
Gates Rubber Co., The, (13)
General Resource Corp., (1, 6, 8)
General Scientific Equipment Co., (11, 12)
Goodall Rubber Co., (11, 12)
Goodrich, B. F. Engineered Systems Co., (13)
Goodyear Tire & Rubber Co., (12, 13)
Greenbank Cast Basalt Eng. Co. Ltd., (7, 8)
Greengate Industrial Polymers Ltd., (12)
Grindex CWI Distributing Co., (15, 17)
Heil Process Equipment Co., Div. of Dart Industries, Inc., (8, 11, 16)
Hercules Inc., (8)
ITT Grinnell Corp., (11, 14, 15)
ITT Harper, (16)
Irathane Systems, Inc., (13)
Jennmar Corp
Johnston Morehouse Dickey Co., (11)
Jones & Laughlin Steel Corp., (14, 17)
Kaiser Aluminum & Chemical Corp., (1)
Kalenborn, (7, 8, 12)
Kinetics, Inc., (8)
Lee Supply Co., Inc., (1, 2, 9, 11, 13, 14, 15, 16, 18, 20)
Linatex Corp. of America, (13)
Logan Corp., (11, 17)
Midland Pipe & Supply Co., (1, 8, 13, 16)
National Mine Service Co., (2, 11)
Naylor Pipe Co., (13, 15, 16)
Peabody ABC, (11)
Phelps Dodge Industries, Inc., (5, 8)
Philips Products Co., Inc., (11)
Preiser/Mineco Div., Preiser Scientific Inc., (11)
Red Valve Co., Inc., (12)
Republic Steel Corp., (8, 9, 14, 16, 17, 18)
Reynolds Metals Co., (1, 3)
Rubber Engineering & Mfg. Co., (12, 13)

Ryerson, Joseph T., & Son, Inc., (1, 8, 11, 14, 16, 17)
Smith, O Inland Inc. Reinforced Plastics Div., (8, 11, 20)
Stellite Div., Cabot Corp., (8)
Trelleborg Rubber Co., Inc., (12)
Tricon Metals & Services, Inc., (8, 11, 14, 16, 17)
Tube Turns Div., Chemetron Piping Systems, (17)
Union Carbide Corp., (8)
Uniroyal, Inc., (12)
United McGill Corp., (1, 11, 15)
United States Steel Corp., (1, 7, 8, 9, 11, 14, 16, 17, 18)
Valley Steel Products Co
West Virginia Belt Sales & Repairs Inc., (11, 12, 13)
Whittaker Corp., (6, 7, 8, 14, 17)
Wilson, R. M., Co., (2, 8, 20)
Workman Developments, Inc., (8, 11)
Youngstown Sheet & Tube Co., The, (8, 11, 14, 17)

PIPE ACCESSORIES

1 COUPLINGS
2 COUPLINGS, FLEXIBLE
3 COUPLINGS, GROOVED
4 COVERINGS
5 FITTINGS, BRASS & BRONZE
6 FITTINGS, CAST-IRON
7 FITTINGS, MALLEABLE-IRON
8 FITTINGS, FLANGES-FABRICATION, WELDING
9 FITTINGS, FORGED STEEL
10 FITTINGS, PLASTIC
11 FITTINGS, RUBBER
12 FITTINGS, STAINLESS STEEL
13 FLANGES, FORGED, STAINLESS, ALLOY
14 GROOVERS
15 HANGERS
16 REPAIR CLAMPS, SLEEVES
17 FITTINGS, CAST STEEL

Acker Drill Co., Inc., (1)
Adams Equipment Co., Inc., (1, 5, 12)
Aeroquip Corp., (1, 2, 8, 9)
Ampco Metal Div., Ampco-Pittsburgh Corp., (5)
Anchor Coupling Co., Inc., (1, 5, 7, 8, 9)
Anixter Mine & Smelter Supply, (14)
A.T.O Inc., (1, 5, 15)
Babcock & Wilcox, (8, 12)
Bethlehem Steel Corp., (9, 13)
Big Sandy Electric & Supply Co., Inc., (3, 6, 7)
Bowman Distribution, Barnes Group, Inc., (1, 6, 7)
C F & I Steel Corp., (1)
Campbell Chain Co., (15)
Certain-Teed Products Corp., Pipe & Plastics Group (1, 10)
Clayton Mark-Pacific Valves, Div. of Mark Controls Corp., (1)
Continental Rubber Works, Sub. of Continental Copper & Steel Industries, Inc., (11)
Contractors Warehouse Inc., (1, 3)
Dresser Manufacturing, Div. Dresser Industries, Inc., (1, 2, 5, 7, 10, 16)
du Pont de Nemours, E. I. & Co. Inc., (10)
Dunron Co., Inc., The (1, 6)
ESCO Corp., (8, 10, 12, 13)
Fairbanks Co., The (7)
Fairmont Supply Co., (1, 3, 6, 7, 8, 9, 10, 15, 16)
Fastener House, Inc., (15)
Federal-Mogul Corp., (10)
Fiberglass Resources Corp., (1, 10, 16)
Flexible Valve Corp., (11)
Foster, L. B., Co., (1)
General Resource Corp., (1)
Goodall Rubber Co., (10, 11)
Greenbank Cast Basalt Eng. Co. Ltd., (1, 8, 15)
Gustin Bacon Div., Aeroquip Corp., (1, 3, 6, 7, 9, 12, 14)
ITT Grinnell Corp., (1, 2, 5, 6, 7, 8, 9, 10, 12, 13, 15, 17)
ITT Holub Industries, (15)
Imperial-Eastman Corp., (1, 5, 10)
Industrial Rubber Products Co., (10, 11, 12, 13)
Johnston-Morehouse-Dickey Co., (1, 3, 10)
Jones & Laughlin Steel Corp
Ladish Co., (1, 8, 9, 12, 13)
Lee Supply Co., Inc., (1, 3, 6, 7, 10, 14, 15, 16, 17)
Le-Hi Valve & Coupling, Hose Products Div., Parker-Hannifin Corp., (1, 3, 5, 6, 7, 9, 10, 12)
Midland Pipe & Supply Co., (8, 12, 13)
National Mine Service Co., (1, 3)
Naylor Pipe Co., (8, 12)
Ohio Brass Co., (7, 15)
Parker-Hannifin Corp., Tube Fittings Div., (5, 9, 12)
Phelps Dodge Industries, Inc., (1, 4, 5, 8)
Phillips Products Co., Inc., (10)
Plymouth Rubber Co., Inc., (4)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 10)
Red Valve Co., Inc., (2, 11)
Seton Name Plate Corp., (4)
Smith, A. O. Inland Inc. Reinforced Plastics Div., (10)
Spraying Systems Co., (5)
Stratoflex, Inc., (1, 5, 8, 12, 13)
Thor Power Tool Co., (1)
Trelleborg Rubber Co., Inc., (1)
Tube Turns Div., Chemetron Piping Systems, (8, 9, 12, 13)
United States Steel Corp., (1, 2, 3, 6, 7, 8, 9, 12, 13, 14, 16)
Valley Steel Products Co
Victaulic Co. of America, (1, 2, 3, 6, 7, 12, 14, 16)
Wachs, E. H., Co
Weatherhead Co., The (1, 5, 9, 12)
West Virginia Belt Sales & Repairs Inc., (1, 10)
Wiggins Connectors Div., Delaval Turbine Inc., (2)
Wilson, R. M., Co., (1, 10)
Workman Developments, Inc., (1, 10, 16)

PIPE FABRICATION, WELDING

American Alloy Steel, Inc
Ampco Metal Div., Ampco-Pittsburgh Corp
Dravo Corp
Foster, L. B., Co
Greenbank Cast Basalt Eng. Co. Ltd
Lively Mfg. & Equipment Co
McLaughlin Mfg. Co
Midland Pipe & Supply Co
Rubber Engineering & Mfg. Co
Stearns-Roger Inc
Valley Steel Products Co
Wachs, E. H., Co
Workman Developments, Inc

POLLUTION-CONTROL SYSTEMS

1 ACID MINE DRAINAGE
2 SOLIDS REMOVAL FROM WATER
3 DUST & FUMES

Aerofall Mills Ltd., (3)
Aggregates Equipment Inc., (3)
Air Correction Div., UOP, (3)
Air Pollution Control Operations, FMC Corp., (3)
American Air Filter Co., Inc., (3)
American Alloy Steel Inc., (1, 2, 3)
American Meter Div., Singer Co., The (1)
American Standard, Industrial Products Div., (3)
A.T.O Inc
Badger Construction Co., Div. of Mellon-Stuart Co., (1, 2, 3)
Betz Laboratories, (2)
Bigelow-Liptak Corp., (3)
Bird Machine Co., Inc., (2)
Calgon Corp., (2)
Conwed Corp., Environmental Products Div
Crane Co
Davis Instrument Mfg. Co., (3)
Dorr-Oliver Long Ltd., (1, 2)
Dowell Div. of the Dow Chemical Co., (1, 2, 3)
Dravo Corp., (1, 2, 3)
Ducon Co., Inc., The (3)
Eaton Corp., Industrial Drives Div., (2)
Environmental Equip. Div., FMC Corp., (2, 3)
Envirotech Corp., Eimco BSP Div., (1, 2)
Eriez Magnetics, (2)
Fairbanks Morse Engine Div., Colt Industries, (2)
Ferro-Tech Inc., (1, 2, 3)
Fiberglass Resources Corp
Finn Equipment Co
Fuller Co., A Gatx Co., (3)
General Resource Corp., (3)
Hayden Nilos Conflow Ltd., (3)
Heil Process Equipment Co., Div. of Dart Industries, Inc., (1, 2, 3)
Hendrick Mfg. Co., (1)
Heyl & Patterson, Inc., (1, 2, 3)
Holley, Kenney, Schott, Inc., (1, 2, 3)
Industrial Contracting of Fairmont, Inc., (1, 2, 3)
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc., (1, 2, 3)
Jeffrey Mfg. Div., Dresser Industries Inc., (2)
Johnson-March Corp., The, (3)
Joy Mfg. Co., Denver Equipment Div
Kay Ray Inc., (2)
Koch Engineering Co., Inc., (3)
Koppers Co., Inc., (1, 2, 3)
Krebs Engineers, (3)
Lively Mfg. & Equipment Co., (2, 3)
McDowell-Wellman Engrg. Co., (3)
McNally Pittsburg Mfg. Corp., (2)
MikroPul Corp., (3)
Mining Equipment Co., A Unit of General Signal (1)
Mott, B. H., & Sons, Inc., (1)
Nalco Chemical Co., (1, 2)
National Car Rental Systems Inc., Mudcat Div., (2)
Norton Co., (3)
Numonics Corp
NUS Corp., Robinson & Robinson Div., (1, 2, 3)
Parkson Corp., (1, 2)
Peterson Filters & Engineering Co., (2)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 3)
Reeu Manufacturing, (3)
Research-Cottrell, Inc., (3)
Rexnord Inc., (1, 2)
Sala International, (2)
Sauerman Bros., Inc., (2)
Shirley Machine Co., Div. Tasa Corp., (1)
Treadwell Corp
Trelleborg Rubber Co., Inc., (3)
Unifloc Limited
Union Carbide Corp., (2)
United McGill Corp., (3)
WEMCO Div., Envirotech Corp., (2)
Western Precipitation Div., Joy Mfg. Co., (3)
Westinghouse Electric Corp., (1, 2, 3)
Wheelabrator-Frye Inc., Air Pollution Control Div., (3)
Willis & Paul Corp., The (3)

PREPARATION - PLANT BUILDERS

Allen & Garcia Co
Badger Construction Co., Div. of Mellon-Stuart Co
Daniels Company, The
Dravo Corp
FMC Corp., Link-Belt Material Handling Systems Div
Fairfield Engineering Co
GEOMIN
Head Wrightson & Co. Ltd
Heyl & Patterson, Inc
Holley, Kenney, Schott, Inc
Industrial Contracting of Fairmont, Inc
Jeffrey Mfg. Div., Dresser Industries Inc
Jenkins of Retford Ltd
KHD Industrieanlagen AG, Humboldt Wedag
Lively Mfg. & Equipment Co
Long-Airdox Co., A Div. of the Marmon Group, Inc
McNally Pittsburg Mfg. Corp
Minerals Processing Co., Div. of Trojan Steel Co
Pullman Torkelson Co
Rish Equipment Co., Material Handling Systems Div
Roberts & Schaefer Co
Roller Corp
Unifloc Limited
Wilmot Engineering Co

PREPARATION PLANTS, PORTABLE

GEOMIN
Heyl & Patterson, Inc
Industrial Contracting of Fairmont, Inc
Jenkins of Retford Ltd
Lively Mfg. & Equipment Co
Mintec International, Div. of Barber-Greene
Sala International
Unifloc Limited
Wilmot Engineering Co
Wilson, R. M., Co

PULVERIZERS

1 COAL
2 FURNACE-FEED
3 LABORATORY

Aerofall Mills Ltd., (1, 2, 3)
American Pulverizer Co., (1)
Anvster Mine & Smelter Supply, (3)
British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch), (1, 3)
C.E. Power Systems, Combustion Eng., Inc., (1)
C.E. Raymond/Bartlett-Snow, Div. Combustion Engineering, Inc., (1, 2, 3)
GEC Mechanical Handling Ltd., (1)
Gruendler Crusher & Pulverizer Co., (1, 2, 3)
Hammermills, Inc., Sub. of Pettibone Corp., (1)
Hewitt-Robins Div., Litton Systems, Inc., (1)
Holmes Bros. Inc., (3)
Jeffrey Mfg. Div., Dresser Industries Inc., (1)
K-G Industries, Inc.
KHD Industrieanlagen AG, Humboldt Wedag, (1, 3)
Kennedy Van Saun Corp. Sub. of McNally Pittsburg, (1)
• Koppers Co., Inc., (1)
Majac Div., Donaldson Co., (1)
Mine & Smelter Industries, (3)
Morse Bros. Machinery Co., (3)
Preiser/Mineco Div., Preiser Scientific Inc., (3)
Pulverizing Machinery, Div. of MikroPul Corp., (1, 3)
Sodlesl, Inc., (3)
Stedman Fdy. & Mach. Co., (1, 3)
Steel Heddle Mfg. Co. Industrial Div., (1)
Sturtevant Mill Co., (3)
Williams Patent Crusher & Pulv. Co., (1, 2, 3)
• Wilson, R. M. Co., (1, 2, 3)
Workman Developments Inc., (3)

PUMP LININGS

Amsco Div., Abex Corp
Equipment Mfg. Services, Inc
Fairmont Supply Co
Galigher Co., The
Holz Rubber Co., A Randron Div
Linatex Corp. of America
RM Roll Products Co., Div. Raybestos-Manhattan, Inc
Stonhard, Inc
West Virginia Belt Sales & Repairs Inc

PUMPS

1 CENTRIFUGAL
2 CORROSION - RESISTANT
3 DIAPHRAGM
4 DRUM
5 FROTH-HANDLING
6 METERING
7 PISTON & PLUNGER
8 PRESSURE-TESTING
9 PRIMING
10 SAND & ABRASIVE HANDLING
11 SLURRY, SOLIDS-HANDLING
12 SUBMERSIBLE
13 SUMP
14 TRANSFER
15 TRASH & SLUDGE
16 VERTICAL CENTRIFUGAL & TURBINE
17 POWER HYDRAULIC
18 EXPLOSIONPROOF

AMF Inc., (3, 6, 7)
A-S-H Pump, Div. of Envirotech Corp., (1, 2, 10, 11, 13, 16)
Abex Corp., Denison Div., (17)
Acker Drill Co., Inc., (7)
Adams Equipment Co., Inc., (1, 2, 7)
Alemite & Instrument Div., Stewart-Warner Corp., (2, 4, 14)
Allis-Chalmers, (1, 2, 10, 11, 12, 15, 16)
American Crucible Products Co., (1, 12, 13)
Ampco Metal Div., Ampco-Pittsburgh Corp., (1, 2)
Amsco Div., Abex Corp., (2, 10, 11, 15)
Anderson Electric Corp., (17)
Aro Corp., The, (4, 6, 7, 14)
Atlas Copco, Inc., (1, 3)
Aurora Pump, Unit of General Signal, (1, 2, 13, 16)
Barrett, Haentjens Co., (1, 2, 5, 9, 10, 11, 12, 13, 16)
Beckman Instruments, Inc., (6)
BIF, a unit of General Signal, (3, 6, 7)
Byron Jackson Pump Div., Borg Warner Corp., (1, 2, 12, 13, 14, 16)
Calgon Corp., (2, 3, 6, 7, 14)
Canton Stoker Corp., (2, 7, 10, 11, 14, 15, 18)
Carborundum Company
Carver Pump Co., (1, 2, 3, 8, 9, 10, 11, 13, 14, 15, 16)
Chicago Pneumatic Equipment Co., (12, 13, 15)
CompAir Construction & Mining Ltd., (1, 12, 13, 15)
Contractors Warehouse Inc., (10, 11, 12, 13, 15, 18)
Crane Co., (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16)
Crisafulli Pump Co., Inc., (1, 11, 12, 13, 15, 16, 17, 18)
Dean Brothers Pumps, Inc., (1, 2, 14, 16, 18)
Dorr-Oliver Inc., (1, 2, 3, 11)
Dorr Oliver Long Ltd., (1, 2, 3, 11)
Dresser Mining Services & Equipment Div., (3, 7)
Duff Norton Co., (17)
Duriron Co., Inc., The, (1, 2, 3, 9, 16)
Dynex Div., Applied Power Inc., (17)
ENERPAC, Div. of Applied Power Inc., (7, 8)
English Drilling Equipment Co. Ltd., (7)
Environmental Equip. Div., FMC Corp., (1, 11, 12, 13, 14, 15, 16)
E Power Industries Corp., (14)
FMC Corp., Agricultural Machinery Div., (2, 7, 8, 14)
FMC Corp., Pump Div., (1, 2, 12, 13, 14, 16)
Federal Supply & Equipment Co., Inc., (8, 17)
Fire Protection Supplies Inc., (1, 3, 9, 15)
Flood City Brass & Electric Co., (1, 2, 7)
Flygt Corp., (2, 10, 11, 12, 13, 15, 18)
Fuller Co., A Gatx Co., (1, 10, 18)
GEC Mechanical Handling Ltd., (1, 2, 10, 11, 13, 16)
Galigher Co., The, (1, 2, 5, 10, 11, 13, 14)
Gardner Denver Co., (2, 3, 7, 8, 11, 12, 13, 14, 18)
General Scientific Equipment Co., (4)
Gorman-Rupp Co., The, (1, 2, 3, 6, 9, 11, 12, 13, 14, 15)
Goulds Pumps, Inc., (1, 2, 9, 11, 12, 13, 14, 16, 18)
Goyne Pump Co., (1, 2, 10, 11, 13, 16)
Grindex-CWI Distributing Co., (10, 12, 13, 15, 18)
Gulf Oil Corp., Dept. DM
Gullick Dobson Intl. Ltd., (1)
Guyan Machinery Co., (1, 2, 3, 7, 10, 11, 12, 13, 15)
Hardman Inc., (6)
Homelite Div., Textron Inc., (1, 3, 12, 15)
Hulburt Oil & Grease Co., (4)
Humboldt-Irwin Co., (17, 18)
Hydraulic Products Inc., (17)
Hydreco, A Unit of General Signal, (17)
Hydr-O-Matic Pump Div., Weil-McLain Co., Inc., Claremont & Baney, (1, 3, 9, 11, 12, 13)
Industrial Rubber Products Co., (1, 3, 4, 7, 9, 12, 13, 14, 15, 16, 18)
Ingersoll-Rand Co., (1, 2, 7, 10, 11, 12, 13, 14, 15, 16)
Jaeger Machine Co., (1, 3, 15)
Jemmer Corp
Johnston Pump Co., (2, 12, 13, 14, 16, 18)
Johnston Pump Co., Pittsburgh Branch, (2, 12, 13, 14, 16)
Joy Mfg. Co., Denver Equipment Div., (1, 2, 3, 5, 6, 10, 11, 13, 16)
Joy Mfg. Co. (U.K.) Ltd., (11)
KHD Industrieanlagen AG, Humboldt Wedag, (1, 10, 11, 13, 16)
Labour Pump Co., (1, 2, 5, 9, 11, 13, 14, 16, 18)
Lawrence Pumps, Inc., (1, 2, 9, 10, 11, 13, 14, 16)
Lee Supply Co., Inc., (1, 2, 3, 7, 11, 12, 13, 14, 15, 16, 18)
Le Roi Div., Dresser Industries, Inc., (3, 12, 13)
Lightning Industries, Inc., (2, 10, 11)
Linatex Corp. of America, (1, 10, 11, 13)
Lincoln St. Louis Div. of McNeil Corp., (2, 4, 7, 14)
Logan Corp., (11, 12, 15, 16)
Lucas Industries, Fluid Power Div., (17)
McNally Pittsburg Mfg. Corp., (1)
Megator Corp., (3, 6, 9, 13, 14)
Midland Pump, LFE Fluids Control Div., (1, 2, 3, 10, 11, 12, 13, 15)
Mineral Services Inc., (1, 10, 11, 13)
Mining Developments Ltd., (13)
Mining Progress, Inc., (7)
Minnesota Automotive Inc., (1, 14)
Morris Pumps, Inc., (1, 2, 5, 10, 11, 12, 13, 14, 15, 16)
Nagle Pumps, Inc., (1, 2, 9, 10, 11, 12, 13, 16)
Nash Engineering Co., (9)
National Car Rental Systems Inc., Mudcat Div., (11)
National Environmental Inst. Inc., (2)
National Supply Co., Div. of Armco Steel Corp., (7, 17)
Peabody Barnes, (1, 2, 3, 7, 9, 10, 11, 12, 13, 14, 15)
Pettibone Corp., (10, 11)
Porter, H. K., Inc., (17)
Porto Pump, Inc., (8)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 2, 3, 4, 6, 7)
Prosser Industries, Div. of Purex Corp., (1, 3, 12, 13)
Rexnord Inc., (17)
Robbins & Myers, Inc., (2, 5, 6, 9, 10, 11, 14, 15)
Sala International, (1, 2, 5, 10, 11, 13, 16)
Sala Machine Works Ltd., (1, 2, 5, 11, 13, 16)
Sperry Vickers Div., Sperry Rand Corp., (17)
Sprague & Henwood, Inc., (7)
Stanadyne/Hartford Div., (7, 14)
Stanco Mfg. & Sales Inc., (1, 2, 10, 11, 12, 15, 18)
Sundstrand Fluid Handling, Div. Sundstrand Corp., (1, 2, 8, 14, 17, 18)
T & T Machine Co., Inc., (1, 2, 3, 7, 9, 10, 11, 12, 13, 15, 16, 18)
Taber Pump Co., Inc., (1, 2, 11, 13, 14, 16, 18)
Templeton, Kenly & Co., (17)
Thomas Foundries Inc., (1, 10, 11, 15)
Thor Power Tool Co., (11, 12, 13)
TRW Mission Mfg. Co., Div. of TRW Inc., (1)
Uniflox Limited
Union Carbide Corp., (1, 2)
United States Steel Corp
Valley Steel Products Co., (12, 16)
Viking Oil & Machinery Co., (5, 14)
Wachs, E. H., Co., (12, 17)
Wajax Industries Ltd., (1, 3, 7, 10, 11, 12, 13, 16)
Warman International, Inc., (1, 2, 5, 10, 11)
Warren Rupp Co., The, (1, 2, 3, 6, 7, 9, 10, 11, 12, 13, 14, 15, 18)
WEMCO Div., Envirotech Corp., (1, 2, 5, 10, 11, 12, 13, 14, 15)
West Virginia Armature Co., (11, 13)
West Virginia Belt Sales & Repairs Inc., (1, 2, 7, 10, 12, 13)
Wilfley, A. R., & Sons, (1, 2, 5, 10, 11, 14)
Wilson, R. M., Co., (1, 2, 7, 11, 12, 13, 15, 16, 18)
Worthington Pump Inc., (1, 2, 7, 11, 12, 13, 15, 16)

RAILROAD CAR LOADING

(SEE LOADING EQUIPMENT, R.R CAR; UNIT-TRAIN LOADING)

RAILROADS, RAILWAYS

Atlantic Track & Turnout Co
Atlas Railroad Construction Co
Baltimore & Ohio R.R. Co
Bessemer & Lake Erie R.R
Consolidated Railway Corp
Dravo Corp
Louisville & Nashville RR
Midwest Steel Div., Midwest Corp

RAILROAD CARS

ACF Industries, Inc
Bethlehem Steel Corp
Firstmark Morrison Inc
Greenville Steel Car Co
McDowell-Wellman Engrg. Co
Ortner Freight Car Co
Pullman Standard Div., Pullman Inc
Whittaker Corp

REAGENTS

American Cyanamid Co., Industrial Chemicals & Plastics Div
American Minechem Corp
Ashland Chemical Co
Beckman Instruments, Inc
Calgon Corp
du Pont de Nemours, E. I. & Co. Inc
Fisher Scientific Co
Hercules Inc
Preiser/Mineco Div., Preiser Scientific Inc
Riverside Polymer Corp
Union Carbide Corp

RECLAMATION

1 TREES OR PLANTS
2 SEEDING
3 SEEDING EQUIPMENT
4 EROSION CONTROL

Conwed Corp., Environmental Products Div., (2)
Finn Equipment Co. (3)
Gulf States Paper Corp. (4)
Hanson, R.A., Disc. Ltd
Hardy Plants
Reinco Industries (2, 3)
U. S. Gypsum Co. (2)

RECORDERS

1 LABORATORY
2 OPERATING HOUR
3 TEMPERATURE

Acco, Bristol Div. (1, 3)
American Meter Div., Singer Co., The, (3)
Babcock & Wilcox (3)
Bacharach Instrument Co., Mining Div. (1, 2, 3)
Bausch & Lomb, SOPD Div. (1)
Beckman Instruments, Inc. (1, 3)
Capital Controls Co. (1)
Fisher Scientific Co. (1, 3)
Foxboro Co., The (1, 2, 3)
General Electric Co., DC Motor & Generator Dept. (2)
General Electric Co., Industrial Sales Div. (1, 2, 3)
GenRad (1)
Honeywell Inc., Process Control Div. (1, 2, 3)
Leeds & Northrup Co. (1, 3)
Measurement & Control Systems Div., Gulton Industries Inc. (1, 3)
Mineral Services Inc. (2)
National Environmental Inst. Inc.
Preiser Mineco Div., Preiser Scientific Inc. (1, 2, 3)
Sangamo Electric Co. (1)
Sprengnether, W. F., Instrument Co. Inc., (1)
TOTCO Div. Baker Oil Tools, Inc. (2)
Westinghouse Electric Corp. (3)

RIVER-LOADING PLANTS

American Commercial Barge Line Co.
Badger Construction Co., Div. of Mellon Stuart Co.
Dravo Corp.
Fairfield Engineering Co.
Heyl & Patterson, Inc.
Jenkins of Retford Ltd
McDowell Wellman Engrg. Co.
Mintec/International, Div. of Barber Greene
Treadwell Corp.
Webb, Jervis B., Co.

REGULATORS

1 PRESSURE
2 TEMPERATURE
3 VOLTAGE
4 WATER LEVEL

Adams Equipment Co., Inc., (1, 2)
Allis Chalmers, (3)
American Meter Div., Singer Co., The (1)
American Rectifier Corp., (3)
Anixter Mine & Smelter Supply (1)
Aro Corp., The, (1)
Beckman Instruments, Inc., (1, 3)
CSE Mine Service Co., (1)
Cashco, Inc., (1, 2, 4)
Compton Electrical Equipment Corp., (3)
Duff Norton Co., (1)
FMC Corp., Agricultural Machinery Div.
Fisher Controls Co., (1)
Flygt Corp., (4)
Foxboro Co., The, (1, 2)
General Electric Co., Industrial Sales Div., (1, 2, 3)
General Equipment & Mfg. Co., Inc., (3)
GenRad, (3)
Hayden Nilos Conflow Ltd., (1)
Honeywell Inc., Process Control Div., (1, 2, 4)
Kay-Ray Inc., (4)
Lincoln St. Louis Div. of McNeil Corp., (1)
Louis Allis Div., Litton Industrial Products Inc., (3)
McGraw-Edison Co., Power Systems Div., (3)
Measurement & Control Systems Div., Gulton Industries Inc., (1, 2)
Modern Engineering Co., (1)
Ohio Transformer Corp., (3)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 2, 3, 4)
Prestolite Electrical Div. of Eltra Corp. (3)
Rapid Electric Co., Inc., (3)
Scott Aviation, A Div. of A-T-O, Inc., (1)
Spraying Systems Co., (1)
Thor Power Tool Co., (1)
Union Carbide Corp., (1)
Unique Products Co., (2, 4)
Westinghouse Electric Corp., (3)
Wiegand, Edwin L., Div., Emerson Elec. Co., (2)

SAFETY EQUIPMENT AND ACCESSORIES

1 SAFETY BELTS
2 SAFETY DISPLAYS, SIGNS
3 SAFETY FOOTGEAR, LEATHER
4 SAFETY FOOTGEAR, RUBBER
5 SAFETY HEADGEAR
6 SAFETY HOOKS
7 SAFETY SIGNS, REFLECTORIZED
8 SAFETY SPECTACLES
9 SELF-RESCUERS

AO Safety Products, Div. of Amer. Optical Corp., (5, 8)
Aldon Company, The (7)
American Optical Corp. (2, 5, 8)
A-T-O Inc.
Bacharach Instrument Co., Mining Div.
Bausch & Lomb, SOPD Div. (5, 8)
Big Sandy Electric & Supply Co., Inc.
Bowman Distribution, Barnes Group, Inc. (2, 5, 6, 7, 8)
Bullard, E. D., Co., (5, 6)
CSE Mine Service Co., (5, 8)
Crosby Group, (6)
Dixon Valve & Coupling Co.
du Pont de Nemours, E. I. & Co. Inc.
Fairmont Supply Co., (5, 8)
Fibre-Metal Products Co., (5, 8)
Fire Protection Supplies Inc., (2, 4, 5, 7, 8)
General Scientific Equipment Co. (1, 2, 3, 4, 5, 6, 7, 8, 9)
Goodall Rubber Co.
Goodrich, B. F., Engineered Systems Co., (4)
Grindex CWI Distributing Co., (4)
Hobart Bros. Co., (5, 8)
Hughes Image Devices
Hy Test Safety Shoes Div., International Shoe Co., (3)
Industrial Rubber Products Co., (4, 5)
Lehigh Safety Shoe Co., (3, 4)
3 M Co. (2, 5, 7)
Mine Safety Appliances Co. (1, 2, 5, 6, 7, 8, 9)
National Mine Service Co., (5, 7, 8, 9)
Norton Co. (5)
[illegible] Inc.
Preiser/Mineco Div., Preiser Scientific Inc., (2, 3, 4, 7)
Pulmosan Safety Equip. Co., (5, 6, 8)
Red Wing Shoe Co., Inc., (3)
Rock Tools, Inc.
Rose Manufacturing Co., (1)
Sala International, (6)
Servus Rubber Co., (4)
Seton Name Plate Corp., (2, 7)
Shannon Optical Co., Inc., (5, 7, 8)
Speakman Co.
Trelleborg Rubber Co., Inc., (4)
Tube-Lok Products Div. of Portland Wire & Iron
Uniroyal Inc., (4)
Uni-Tool Attachments, Inc.
Warn Industries
Welsh Div. of Textron, (5, 8)
Willson Products Div., ESB, Inc.

SAMPLERS

1 COAL
2 COAL, AUTOMATIC

Commercial Testing & Engineering Co., (1, 2)
Fairfield Engineering Co., (1, 2)
Gilson Screen Co. (1, 2)
Holmes Bros. Inc., (1, 2)
Industrial Contracting of Fairmont, Inc.
Joy Mfg. Co., Denver Equipment Div.
Lively Mfg. & Equipment Co.
McNally Pittsburg Mfg. Corp. (1, 2)
Preiser/Mineco Div., Preiser Scientific Inc. (1, 2)
Ramsey Engineering, Co., (1, 2)
Redding Co., James A., (1, 2)
Sala International
Sala Machine Works Ltd., (1, 2)
Sturtevant Mill Co., (1, 2)
Wilson, R. M., Co., (1, 2)
Workman Developments, Inc., (1, 2)

SCALE-WEIGHT RECORDERS

Cardinal Scale Mfg. Co.
Concrete Equipment Co., Inc.
Fairbanks Weighing Div., Colt Industries
Gardner Denver Co.
Howe Richardson Scale Co.
K-Tron Corp.
Railweight, Inc.
Ramsey Engineering, Co.
Revere Corp. of America, Sub. of Neptune Intl. Corp.
Streeter Amet, Div. of Mangood Corp.
Thayer Scale Hyer Industries
Thurman Scale Co. Div. Thurman Mfg. Co.
West Virginia Belt Sales & Repairs Inc.

SCALES

(SEE ALSO CONVEYOR WEIGHERS, LABORATORY TESTING EQUIPMENT)

1 MINE-CAR WEIGHING
2 R.R. CAR WEIGHING
3 TRUCK WEIGHING

ASEA Inc. (1, 2)
Auto Weigh Inc.
Baltimore & Ohio R.R. Co. (2)
Cardinal Scale Mfg. Co.
Concrete Equipment Co., Inc.
Duplex Mill & Mfg. Co., (3)
Fairbanks Weighing Div., Colt Industries (1, 2, 3)
Gardner Denver Co. (1, 2, 3)
Howe Richardson Scale Co. (1, 2, 3)
Inflo Resometric Scale Inc.
Kay-Ray Inc.
Kilo-Wate Inc., (2, 3)
Lively Mfg. & Equipment Co., (2, 3)
Logan Corp., (3)
Mineral Services Inc., (2)
Railweight Inc., (1, 2, 3)
Ramsey Engineering Co.
Revere Corp. of America, Sub. of Neptune Intl. Corp. (1, 2, 3)
Streeter Amet, Div. of Mangood Corp. (1, 2, 3)
Texas Nuclear
Thurman Scale Co. Div. Thurman Mfg. Co. (1, 2, 3)
West Virginia Belt Sales & Repairs Inc. (1, 2, 3)
Wilson, R. M., Co. (1, 2, 3)
Winslow Scale Co. (3)

SCRAPER TIPS, TEETH

Amsco Div., Abex Corp.
Caterpillar Tractor Co.
ESCO Corp.
Hensley Industries Inc.

SCRAPERS

1 SELF-POWERED, EARTH MOVING
2 SHOT HOLE
3 TRACTOR DRAWN, EARTH MOVING
4 UNDERGROUND

Card Corp. (4)
Caterpillar Tractor Co. (1, 3)
Clark Equipment Co., Construction Machinery Div. (1)
Deere & Co. (1)
Fiat Allis Construction Machinery, Inc. (1)
Ford Tractor & Implement, (3)
Hanson, R.A., Disc. Ltd
International Harvester Co., (1)
Joy Mfg. Co., Denver Equipment Div. (4)
Mining Supplies Ltd. (4)
Rish Equipment Co. Intl. (1)
S & S Machinery Sales, Inc., (4)
Terex Div., GMC (1)
WABCO Construction and Mining Equipment Group, an American Standard Co. (1, 3)
Wajax Industries Ltd. (4)

SCREEN-CLOTH HEATERS

CE Tyler Inc.
Hanco International Div. of Hannon Electric Co.
Midwestern Industries, Inc., Screen Heating Transformers Div.
Smico Corp.
Universal Vibrating Screen Co.

SCREEN

1. MESH CLOTH
2. PERFORATED, CENTRIFUGAL DRYERS
3. ROD TYPE
4. RUBBER
5. SPACE CLOTH
6. WEDGE-BAR & WIRE
7. POLYURATHANE

Belleville Wire Cloth Co., Inc., (1)
Bixby Zimmer Engrg. Co., (3, 6)
Bonded Scale & Machine Co., (1, 5, 6)
Buffalo Wire Works Co., Inc., (1, 5)
CE Tyler Inc., (1, 3, 4, 5, 6, 7)
Card Corp., (2)
Centrifugal & Mechanical Industries, Inc., (2, 6)
Cincinnati Rubber Mfg. Co., Div. of Stewart Warner Corp., (4)
Cleveland Wire Cloth & Mfg. Co., (1, 5)
Durex Products, Inc., Natl. Wire Cloth Div., (1, 2, 3, 4, 5, 6)
Fairmont Supply Co., (1, 2, 6)
Greening Donald Co. Ltd., (1, 2, 5)
Guyan Machinery Co., (1)
Harrington & King Perforating, (2)
Hendrick Mfg. Co., (2, 3, 4, 6)
Hewitt Robins Div., Litton Systems, Inc., (1, 3)
Hoyt Wire Cloth Co., (5)
Industrial Contracting of Fairmont, Inc., (1)
Iowa Manufacturing Co., (1)
Jeffrey Mfg. Div., Dresser Industries Inc.
Johnson Div., Universal Oil Products, (6)
Laubenstein Mfg. Co., (2, 4)
Linatex Corp. of America, (4)
Logan Corp., (1, 2)
Ludlow Saylor Wire Cloth, Div. G.S.I., (1, 5)
McBride Industries Inc.
McKey Perforating Co., Inc., (2)
Midwestern Industries, Inc., Screen Heating Transformers Div., (1, 5)
National Filter Media Corp., (1)
National-Standard Co., Perf. Metals Div., (2, 6)
Redding Co., James A., (1, 2, 3, 4, 5, 6)
Simplicity Engineering, (1)
Smico Corp.
SWECO, Inc., (1)
Trelleborg Rubber Co., Inc., (4)
Unifloc Limited
Wajax Industries Ltd., (4)
Wedge Wire Corp., (2, 6)
West Virginia Belt Sales & Repairs Inc., (1, 4)
Wilson, R. M., Co., (2, 3, 6)
Wire Cloth Enterprises, Inc., (1, 5)

SCREEN PLATE

1. PERFORATED
2. PERFORATED, RUBBER-CLAD

American Alloy Steel, Inc., (1)
Bonded Scale & Machine Co., (1)
Card Corp., (1)
Cleveland Wire Cloth & Mfg. Co.
Durex Products, Inc., Natl. Wire Cloth Div., (1, 2)
Fairmont Supply Co., (1, 2)
Greening Donald Co. Ltd., (1, 2)
Guyan Machinery Co., (1)
Harrington & King Perforating, (1)
Hendrick Mfg. Co., (1, 2)
Hoyt Wire Cloth Co., (1, 2)
International Alloy Steel Div., Curtis Noll Corp., (1)
Iowa Manufacturing Co., (1)
Jeffrey Mfg. Div., Dresser Industries Inc., (1, 2)
Kanawha Mfg. Co., (1)
Laubenstein Mfg. Co., (1, 2)
Linatex Corp. of America, (2)
Logan Corp., (1)
Manganese Steel Forge, Taylor-Wharton Co., Div. of Harsco Corp., (1)
Manufacturers Equipment Co., The
McKey Perforating Co., Inc., (1)
McNally Pittsburg Mfg. Corp., (1)
Mescher Mfg. Co. Inc., (1)
National-Standard Co., Perf. Metals Div., (1)
Portec, Inc., Pioneer Div., (1)
Redding Co., James A., (1, 2)
Smico Corp., (1, 2)
West Virginia Belt Sales & Repairs Inc., (1, 2)
Wilson, R. M., Co., (1, 2)

SCREENS

1. INCLINED STATIONARY
2. TESTING

Aggregates Equipment Inc., (1)
Bixby-Zimmer Engrg. Co., (1)
Bonded Scale & Machine Co., (1)
CE Tyler Inc., (1, 2)
Cleveland Wire Cloth & Mfg. Co., (1)
El-Jay, Inc., (1)
Environmental Equip. Div., FMC Corp., (1)
Fairmont Supply Co., (1)
Gilson Screen Co., (2)
Harrington & King Perforating, (1, 2)
Hendrick Mfg. Co., (1, 2)
Hewitt-Robins Div., Litton Systems, Inc., (1, 2)
Heyl & Patterson, Inc., (1)
Johnson Div., Universal Oil Products, (1, 2)
Laubenstein Mfg. Co., (1, 2)
Ludlow-Saylor Wire Cloth, Div. G.S.I., (1, 2)
Portec, Inc., Pioneer Div., (1)
Preiser/Mineco Div., Preiser Scientific Inc., (2)
Rexnord Inc., Process Machinery Div., (1)
Screen Equipment Co., Div. Hobam Inc., (1)
Smico Corp., (1, 2)
Soiltest, Inc., (2)
SWECO, Inc., (1)
Telsmith Div., Barber-Greene Co., (1)
Universal Vibrating Screen Co., (2)
Wedge Wire Corp., (1)
WEMCO Div., Envirotech Corp., (1)
Wilson, R. M., Co., (1)

SCREENING MACHINES

1. REVOLVING
2. SHAKING
3. VIBRATING

Aggregates Equipment Inc., (2, 3)
Allis-Chalmers, (3)
Allis-Chalmers, Crushing & Screening Equipment, (3)
Barber-Greene Co., (3)
Bonded Scale & Machine Co., (3)
CE Tyler Inc., (1, 2, 3)
Card Corp., (1)
Connellsville Corp., (2)
Deister Concentrator Co. Inc., The, (3)
Deister Machine Co., Inc., (3)
Derrick Mfg. Co., (3)
Dravo Corp., (2, 3)
El-Jay, Inc., (3)
Eriez Magnetics, (3)
FMC Corp., Material Handling Equipment Div., (3)
Fredrik Mogensen AB, (3)
Fuller Co., A Gatx Co., (3)
General Kinematics Corp., (3)
Gruendler Crusher & Pulverizer Co., (1, 3)
Guyan Machinery Co., (3)
Hammermills, Inc., Sub. of Pettibone Corp., (3)
Iowa Manufacturing Co., (3)
Jeffrey Mfg. Div., Dresser Industries Inc., (2, 3)
KHD Industrieanlagen AG, Humboldt Wedag, (1, 2, 3)
Kanawha Mfg. Co., (2)
Krebs Engineers, (2, 3)
Laubenstein Mfg. Co., (1, 2, 3)
Lively Mfg. & Equipment Co., (2, 3)
Logan Corp., (3)
Machinoexport, (1, 3)
McLanahan Corp., (1)
McNally Pittsburg Mfg. Corp., (2)
Midwestern Industries, Inc., Screen Heating Transformers Div., (1, 2, 3)
Mineral Services Inc., (2, 3)
Mintec/International, Div. of Barber Greene, (3)
National Engineering Co., (3)
Portec, Inc., Pioneer Div., (2, 3)
Preiser/Mineco Div., Preiser Scientific Inc., (1, 2, 3)
Rexnord Inc., (3)
Rexnord Inc., Process Machinery Div., (1, 2, 3)
Rish Equipment Co., Material Handling Systems Div.
Rock Industries Machinery Corp., (1, 2, 3)
Screen Equipment Co., Div. Hobam Inc., (3)
Simplicity Engineering, (3)
Smico Corp., (3)
Sprout Waldron, Koppers Co., Inc., (2, 3)
Sturtevant Mill Co., (3)
SWECO, Inc., (2, 3)
Telsmith Div., Barber-Greene Co., (3)
Unifloc Limited
Universal Road Machinery Co., (1)
Universal Vibrating Screen Co., (3)
West Virginia Belt Sales & Repairs Inc., (3)
Wilson, R. M., Co., (2, 3)

SCREENING PLANTS, PORTABLE

Aggregates Equipment Inc.
Allis-Chalmers, Crushing & Screening Equipment
Barber Greene Co.
Bonded Scale & Machine Co.
CE Tyler Inc.
El Jay, Inc.
Gruendler Crusher & Pulverizer Co.
Guyan Machinery Co.
Hammermills, Inc., Sub. of Pettibone Corp.
Hewitt Robins Div., Litton Systems, Inc.
Iowa Manufacturing Co.
Jeffrey Mfg. Div., Dresser Industries Inc.
KHD Industrieanlagen AG, Humboldt Wedag
Mintec/International, Div. of Barber-Greene
Ore Reclamation Co.
Portec, Inc., Pioneer Div.
Rexnord Inc., Process Machinery Div.
Rish Equipment Co., Material Handling Systems Div.
Rock Industries Machinery Corp.
Screen Equipment Co., Div. Hobam Inc.
Telsmith Div., Barber Greene Co.
Wilson, R. M., Co.

SCRUBBERS

1. AIR, GAS
2. DRYER-EXHAUST

Aerofall Mills Ltd., (1)
Aggregates Equipment Inc.
Air Pollution Control Operations, FMC Corp., (1)
American Air Filter Co., Inc., (1, 2)
Babcock & Wilcox, (1)
Bethlehem Steel Corp.
CSE Mine Service Co., (1, 2)
Dravo Corp., (1)
Ducon Co., Inc., The, (1, 2)
Entoleter Inc., (2)
Environeering, Inc., (1, 2)
Environmental Equip. Div., FMC Corp., (1)
Fuller Co., A Gatx Co., (1)
General Resource Corp., (1)
Gundlach, T. J., Machine Co., Div. J. M. J. Industries, Inc.
Hammermills, Inc., Sub. of Pettibone Corp.
Heil Process Equipment Co., Div. of Dart Industries, Inc., (1, 2)
Hunslet Holdings Ltd., Hunslet Engine Works, (1)
Industrial Contracting of Fairmont, Inc., (1, 2)
Johnson-March Corp., The, (1)
Joy Mfg. Co., (1)
Joy Mfg. Co. (U.K.) Ltd., (1)
KHD Industrieanlagen AG, Humboldt Wedag, (1, 2)
Koch Engineering Co., Inc., (1, 2)
Krebs Engineers, (1, 2)
McLanahan Corp.
National Mine Service Co.
Research Cottrell, Inc., (1)
Sly, W. W., Mfg. Co., (1, 2)
Telsmith Div., Barber Greene Co.
United McGill Corp., (1, 2)
Universal Road Machinery Co.
West Virginia Belt Sales & Repairs Inc., (1)
Western Precipitation Div., Joy Mfg. Co., (1)
Wills & Paul Corp., The, (1)

SEPARATORS, HEAVY MEDIUM

(SEE WASHERS, HEAVY MEDIUM)

SIEVES, TESTING

CE Tyler Inc.
Durex Products, Inc., Natl. Wire Cloth Div.
Gilson Screen Co.
Hacker Instruments Inc.
Hendrick Mfg. Co.
Joy Mfg. Co., Denver Equipment Div.
KHD Industrieanlagen AG, Humboldt Wedag

Laubenstein Mfg. Co.
Midwestern Industries, Inc., Screen Heating Transformers Div
Preiser/Mineco Div., Preiser Scientific Inc.
Smico Corp
Soiltest, Inc

SIEVE SHAKERS

CE Tyler Inc
Durex Products, Inc., Natl. Wire Cloth Div
FMC Corp., Material Handling Equipment Div
Gilson Screen Co
Hacker Instruments Inc
Joy Mfg. Co., Denver Equipment Div.
Laubenstein Mfg. Co.
Midwestern Industries, Inc., Screen Heating Transformers Div
Mineral Services Inc
Preiser/Mineco Div., Preiser Scientific Inc
Smico Corp
Soiltest, Inc

SILOS, ASH, COAL, ROCK-DUST & SAND STORAGE

Aggregates Equipment Inc
Armco Steel Corp., Product Info
Badger Construction Co., Div. of Mellon-Stuart Co
Concrete Equipment Co., Inc
Ferro-Tech, Inc
First Colony Corp
Fruehauf Div., Fruehauf Corp
Holmes Bros. Inc
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc
MacDonald Engineering Co
Marietta Concrete Co
Neff & Fry, Inc
Ruttmann Companies

SLUDGE-RECOVERY SYSTEMS

Ametek
Bird Machine Co., Inc
Envirex, Inc
Environmental Equip. Div., FMC Corp
Envirotech Corp., Eimco BSP Div
Fairfield Engineering Co
Feeco International, Inc
Heil Process Equipment Co., Div. of Dart Industries, Inc
Heyl & Patterson, Inc
Holley, Kenney, Schott, Inc
Jeffrey Mfg. Div., Dresser Industries Inc
Joy Mfg. Co., Denver Equipment Div
Kaiser Engineers, Inc
Ray Ray Inc
Rexnord Inc
Sala International
Sauerman Bros., Inc
Unifloc Limited

SPRAY COMPOUNDS, COAL & DUST

Amoco Oil Company
Dowell Div. of the Dow Chemical Co
Exxon Co., U.S.A
Johnson-March Corp., The
Preiser/Mineco Div., Preiser Scientific Inc
Shell Oil Co
Wilson, R. M., Co

SPRAY OILS

Amoco Oil Company
Ashland Oil & Refining Co
Bowman Distribution, Barnes Group, Inc
Exxon Co., U.S.A
Gulf Oil Corp., Dept. DM
Keenan Oil Co
Shell Oil Co
Sun Oil Co
Texaco Inc
Viking Oil & Machinery Co

SPRAYING EQUIPMENT

(SEE ALSO DUSTPROOFING EQUIPMENT)

1. OIL
2. WATER & COMPOUNDS

Ashland Oil & Refining Co., (1)
Austin, J. P., Inc., (2)
BASF Wyandotte Corp., (2)
Bete Fog Nozzle, Inc., (2)
Clayton Mfg. Co., (2)
Delavan Mfg. Co
Dover Conveyor & Equipment Co., Inc., (2)
FMC Corp., Agricultural Machinery Div., (2)
Gammeter, W. F., Co
Hayden-Nilos Conflow Ltd
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc
Jebco, Inc., (2)
Johnson-March Corp., The, (2)
Johnston-Morehouse-Dickey Co., (2)
Lee, A.L., & Co., Inc., (2)
Lee Supply Co., Inc
Lincoln St. Louis Div. of McNeil Corp
Michael Walters Ind.
Preiser/Mineco Div., Preiser Scientific Inc., (2)
Spraying Systems Co., (1, 2)
Viking Oil & Machinery Co
Wilson, R. M., Co., (2)

STACKS

Bethlehem Steel Corp
Canton Stoker Corp
Heil Process Equipment Co., Div. of Dart Industries, Inc
Kanawha Mfg. Co
Treadwell Corp

STACKERS, RECLAIMERS, COAL

Aggregates Equipment Inc
Barber-Greene Co
Concrete Equipment Co., Inc
Continental Conveyor & Equipment Co
DEMAG Lauchhammer
Dover Conveyor & Equipment Co., Inc
Dravo Corp
FMC Corp., Link-Belt Material Handling Systems Div
Fairfield Engineering Co
GEC Mechanical Handling Ltd
Hanson, R.A., Disc., Ltd
Hewitt-Robins Div., Litton Systems, Inc
Heyl & Patterson, Inc
Industrial Contracting of Fairmont, Inc
Iowa Manufacturing Co
Jeffrey Mfg. Div., Dresser Industries Inc
Jenkins of Retford Ltd
Lake Shore, Inc
Marsh, E. F., Engineering Co
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Mintec/International, Div. of Barber-Greene
O & K Orenstein & Koppel AG
Peerless Conveyor & Mfg. Co., Inc
Rexnord Inc., Process Machinery Div
Stephens-Adamson
Webb, Jervis B., Co
Willis & Paul Corp., The
Wilson, R. M., Co

STORAGE PILE PROTECTIVE COATINGS

Adhesive Engineering Co
Dowell Div. of the Dow Chemical Co
Johnson-March Corp., The
Preiser/Mineco Div., Preiser Scientific Inc
Wilson, R. M., Co

STORAGE & RECLAIMING SYSTEMS

Acco, Integrated Handling Systems Div
Alpine Equipment Corp
Barber-Greene Co
Dravo Corp
FMC Corp., Link-Belt Material Handling Systems Div
Fairfield Engineering Co
Feeco International, Inc
GEC Mechanical Handling Ltd
Hanson, R.A., Disc., Ltd
Hewitt-Robins Div., Litton Systems, Inc
Heyl & Patterson, Inc
Holley, Kenney, Schott, Inc
Industrial Contracting of Fairmont, Inc
Iowa Manufacturing Co
Jeffrey Mfg. Div., Dresser Industries Inc
Kaiser Engineers, Inc
Kanawha Mfg. Co
Lively Mfg. & Equipment Co
Long-Airdox Co., A Div. of the Marmon Group, Inc
Marsh, E. F., Engineering Co
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Mintec/International, Div. of Barber-Greene
Neff & Fry, Inc
ORBA Corp
Paceco, A Div. of Fruehauf Corp
Roberts & Schaefer Co
Sauerman Bros., Inc
Stearns-Roger Inc
Stephens-Adamson
Treadwell Corp
Vibranetics, Inc
Webb, Jervis B., Co
Westinghouse Electric Corp
Willis & Paul Corp., The
Wilson, R. M., Co

TABLE DECKS, WASHING

Deister Concentrator Co., Inc., The
Linatex Corp. of America
Poly Hi, Inc
West Virginia Belt Sales & Repairs Inc

TABLES

(SEE WASHERS, COAL, TABLE-TYPE)

TANKS

1. CLARIFYING, SLUDGE-RECOVERY
2. CONCRETE
3. RUBBER LINED
4. STEEL
5. WOOD
6. PLASTIC

ACF Industries, Inc., (4)
ASV Engineering Ltd., (1, 3, 4)
American Alloy Steel, Inc., (4)
Armco Steel Corp., Product Info., (4)
Bethlehem Steel Corp., (1, 3, 4)
Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp., (3)
Concrete Equipment Co., Inc., (4)
Environeering, Inc., (1)
Environmental Equip. Div., FMC Corp., (1, 4)
Equipment Mfg. Services, Inc., (4)
Fabricated Metals Industries, Inc
First Colony Corp., (2)
Galigher Co., The, (3)
Gates Rubber Co., The, (3)
Goodyear Tire & Rubber Co., (3)
Heil Process Equipment Co., Div. of Dart Industries, Inc., (3, 4)
Hendrick Mfg. Co., (1)
Holmes Bros. Inc., (4)
Huwood Irwin Co., (4)
Industrial Contracting of Fairmont, Inc., (1, 4)
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc., (4)
Joy Mfg. Co., Denver Equipment Div., (1, 3, 4)
Kanawha Mfg. Co., (4)
Lee Supply Co., Inc., (4, 6)
Linatex Corp. of America, (3)
Lively Mfg. & Equipment Co., (1, 2, 4)
Marietta Concrete Co., (2)
McNally Pittsburg Mfg. Corp., (1, 4)
Neff & Fry, Inc., (2)
Preiser/Mineco Div., Preiser Scientific Inc., (4, 6)
Rubber Engineering & Mfg. Co., (3)
Ruttmann Companies, (2)
Somerset Welding & Steel Inc., (4)
Stearns-Roger Inc., (3, 4)
Telsmith Div., Barber-Greene Co., (1, 4)
Unifloc Limited
United States Steel Corp., (4)
West Virginia Belt Sales & Repairs Inc., (1, 3, 6)
Willis & Paul Corp., The, (4)
Workman Developments, Inc., (6)

TEMPERATURE INDICATORS, CONTROLLERS

Acco, Bristol Div
Allen Bradley Co
Alnor Instrument Co
American Meter Div., Singer Co., The
Bacharach Instrument Co., Mining Div
Barnes Engineering Co
Beckman Instruments, Inc
Communication & Control Eng. Co. Ltd
Davis Instrument Mfg. Co
Foxboro Co., The
General Electric Co., Industrial Sales Div
General Electric Co., Instrument Products Operation
Honeywell Inc., Process Control Div
Huwood Irwin Co
Leeds & Northrup Co
3 M Co
Measurement & Control Systems Div., Gulton Industries Inc
Pace Transducer Co., Div. of C J Enterprises
Preiser/Mineco Div., Preiser Scientific Inc
Pyott-Boone, Inc
Taylor Instrument Process Control Div. Sybron Corp
Westinghouse Electric Corp

THICKENERS

American Minechem Corp
Calgon Corp
Dorr-Oliver Inc
Enviros, Inc
Enviro-Clear, a Div. of Amstar Corp
Environmental Equip. Div., FMC Corp
Envirotech Corp., Eimco BSP Div
Goodrich, B. F., Chemical Co
Hendrick Mfg. Co
Hercules Inc
Heyl & Patterson, Inc
Joy Mfg. Co., Denver Equipment Div
KHD Industrieanlagen AG, Humboldt Wedag
McNally Pittsburg Mfg. Corp
Mineral Services Inc
Parkson Corp
Resnord Inc
Sala International
Sala Machine Works Ltd
Unifloc Limited
West Virginia Belt Sales & Repairs Inc

THICKENING, STABILIZING, SUSPENDING AGENTS

American Cyanamid Co., Industrial Chemicals & Plastics Div
BASF Wyandotte Corp
Betz Laboratories
Calgon Corp
Dowell Div. of the Dow Chemical Co
GAF Corp
Goodrich, B. F., Chemical Co
Hendrick Mfg. Co
Nalco Chemical Co
Preiser/Mineco Div., Preiser Scientific Inc
Unifloc Limited

TRUCKS & TRACTOR-TRAILERS

1. ON-HIGHWAY
2. OFF-HIGHWAY

Athey Products Corp., (2)
Caterpillar Tractor Co., (2)
Challenge-Cook Bros., Inc., (1, 2)
Cushman-OMC-Lincoln, (2)
Dart Truck Company, (2)
Eimco Mining Machinery, Envirotech Corp., (2)
Euclid, Inc., Sub. of White Motor Corp., (2)
Fairbanks Co., The, (2)
Ford Div. of Ford Motor Co., (1, 2)
Fruehauf Div., Fruehauf Corp., (1, 2)
GMC Truck & Coach Div
Goodbary Engineering Co., (2)
International Harvester Co., (1, 2)
Iowa Mold Tooling Co., Inc., (2)
ISCO Mfg. Co., (2)
Kenworth Truck Co., (1, 2)
Kockums Industri AB, (1, 2)
Kress Corp., (2)
Mack Trucks, Inc., (1, 2)
Oshkosh Truck Corp., (1, 2)
Rish Equipment Co. Intl
Sterling Custom Built Trucks
Terex Div., GMC, (2)
WABCO Construction and Mining Equipment Group, an American-Standard Co., (2)
Wagner Mining Equip., (2)
White Motor Corp.-Truck Group, (1, 2)

UNIT TRAIN STORAGE & LOADING FACILITIES

Baltimore & Ohio R.R. Co
Barber-Greene Co
Daniels Company, The
DEMAG Lauchhammer
Dravo Corp
FMC Corp., Link-Belt Material Handling Systems Div
Fairfield Engineering Co
Fesco International, Inc
GEC Mechanical Handling Ltd
Hanson, R.A., Disc., Ltd
Heyl & Patterson, Inc
Holley, Kenney, Schott, Inc
Industrial Contracting of Fairmont, Inc
Irvin-McKelvy Co., The
Kaiser Engineers, Inc
Kanawha Mfg. Co
Lively Mfg. & Equipment Co
McDowell-Wellman Engrg. Co
McNally Pittsburg Mfg. Corp
Mintec/International, Div. of Barber-Greene
Pullman Torkelson Co
Rish Equipment Co., Material Handling Systems Div
Ruttmann Companies
Stephens-Adamson
Wilson, R. M., Co

VALVE ACTUATORS, OPERATORS

Beckman Instruments, Inc
Cashco, Inc
Clayton Mark-Pacific Valves, Div. of Mark Controls Corp
Crane Co
DeZurik, a Unit of General Signal
Durvon Co., Inc., The
Equipment Mfg. Services, Inc
Fairmont Supply Co
Fisher Controls Co
General Equipment & Mfg. Co., Inc
General Resource Corp
Homestead Industries, Inc
Honeywell Inc., Process Control Div
Jenkins Bros
Measurement & Control Systems Div., Gulton Industries Inc
North American Mfg. Co
Philadelphia Gear Corp
RKL Controls
Raco International, Inc
Rockwell International Flow Control Div
Victaulic Co. of America
Wachs, E. H., Co
Westinghouse Electric Corp
Wilson, R. M., Co

VALVES

1. AIR
2. BLOW-OFF
3. CHECK
4. CONTROL
5. DIAPHRAGM
6. FOOT
7. GATE
8. GLOBE
9. AIR, HYDRAULIC, MOTOR OPERATED
10. NEEDLE
11. ORIFICE
12. PINCH
13. PLUG
14. PUMP
15. RELIEF

HYDRAULIC (SEE HYDRAULIC VALVES)

ACF Industries, Inc., (7, 13, 15)
AMF Inc., (14)
A-S-H Pump, Div. of Envirotech Corp., (3)
Adams Equipment Co., Inc., (3, 6, 10)
Alemite & Instrument Div., Stewart Warner Corp., (1, 4)
American Air Filter Co., Inc., (3, 5)
American Meter Div., Singer Co., The, (1, 4, 5, 10, 15)
Anchor Coupling Co., Inc., (3)
Anchor/Darling Valve Co., (3, 7, 8, 9)
Anixter Mine & Smelter Supply, (1, 2, 3, 4, 6, 7, 8, 10, 11, 12, 15)
Armco Steel Corp., Product Info., (2, 7, 14)
Aro Corp., The, (1, 3, 4, 6, 10, 15)
Babcock & Wilcox, (1, 5, 10, 13)
Barksdale Controls Div./DELAVAL Turbine Inc., (1, 4, 9)
Baw Knox Equipment, Inc., (7)
Bowman Distribution, Barnes Group, Inc., (1, 7)
Branford Vibrator Co., The, Div. of Electro Mechanics, Inc., (1, 2, 6)
Bruning Co., (3, 15)
Cashco, Inc., (1, 2, 3, 4, 5, 8, 9, 10, 11, 13, 14, 15)
Clarkson Co., (4, 5, 12, 14)
Clayton Mark Pacific Valves, Div. of Mark Controls Corp., (1, 2, 3, 4, 5, 6, 7, 8, 9)
Cleveland Armstrong Corp., (7, 9)
Control Concepts, (4)
Crane Co., (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 13, 14, 15)
Daniels Company, The, (12, 14)
DeZurik, a Unit of General Signal, (4, 7, 9, 13)
Dixon Valve & Coupling Co., (1, 3, 4, 10)
Dresser Manufacturing, Div. Dresser Industries, Inc., (3, 7, 9)
Durvon Co., Inc., The, (4, 13)
Dynex Div., Applied Power Inc., (3, 4, 15)
Eaton Corp., World Headquarters, (4)
ENERPAC, Div. of Applied Power Inc., (3, 4, 14, 15)
Equipment Mfg. Services, Inc., (4, 9)
FMC Corp., Agricultural Machinery Div., (14, 15)
FMC Corp., Material Handling Equipment Div., (5)
Fabri-Valve, (3, 7, 9)
Fairbanks Co., The, (1, 2, 3, 7, 8, 10)
Fairmont Supply Co., (3, 6, 7, 8, 10, 13)
Federal Supply & Equipment Co., Inc., (14, 15)
Fisher Controls Co., (1, 4, 8, 12, 15)
Flexible Valve Corp., (4, 12)
Fluid Controls Inc., (3, 4, 9, 10, 15)
Foxboro Co., The, (4, 5, 8, 9, 10)
Fuller Co., A Gatx Co., (3, 7, 9, 15)
GTE Sylvania Inc., (1, 4)
Galigher Co., The, (5, 9, 12)
General Equipment & Mfg. Co., Inc., (1, 4)
General Resource Corp., (3, 4, 5, 7, 15)
Goodall Rubber Co., (14)
Goyne Pump Co., (3, 6, 7, 14)
Gullick Dobson Intl. Ltd., (4)
Gustin Bacon Div., Aeroquip Corp., (13)
Halliburton Services-Research Center, (13)
Hayden Nilos Conflow Ltd., (2, 3, 4, 6, 10, 15)
Heyl & Patterson, Inc., (13)
Homestead Industries, Inc., (1, 4, 9, 13)
Honeywell Inc., Process Control Div., (4, 5, 8)
Huwood Irwin Co., (4, 14, 15)
Hydraulic Products Inc., (15)
ITT Grinnell Corp., (3, 7, 8)
Imperial-Eastman Corp., (1, 3, 4, 5, 8, 10, 13, 15)
Industrial Rubber Products Co., (1, 3, 6, 12)
Jenkins Bros., (1, 2, 3, 4, 7, 8, 9, 10, 13)
Ladish Co., (3, 7, 8)
Lee Supply Co., Inc., (1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13)
Le Hi Valve & Coupling, Hose Products Div., Parker Hannifin Corp., (1)
Linatex Corp. of America, (12)
Lincoln St. Louis Div. of McNeil Corp., (1, 2, 3, 4)
Logan Corp., (3, 6, 7, 8, 13)
Lunkenheimer Co., Div. of Conval Corp., Sub. of Condec Corp., (1, 2, 3, 7, 8, 9, 10, 15)
McNally Pittsburg Mfg. Corp., (3, 7)
Mine & Smelter Industries, (12)
Mineral Services Inc., (4, 7, 12, 14)
Minnesota Automotive Inc., (3)
Modern Engineering Co., (10)
Morgantown Machine & Hydraulics, Inc., Div. Natl. Mine Service Co., (3, 4, 15)
North American Mfg. Co., (1, 4, 9)
Ohio Brass Co., (3, 7, 8)
Parker Hannifin Corp., Tube Fittings Div., (10)
Peabody Barnes, (6)
Phelps Dodge Industries, Inc., (3, 7, 8)
Preiser/Mineco Div., Preiser Scientific Inc., (3, 6, 7, 10, 15)
RKL Controls, (1, 4, 5, 9, 12)
Red Valve Co., Inc., (3, 12)
Research Cottrell, Inc., (1, 3, 7)
Rockwell International Flow Control Div., (2, 3, 7, 8, 9, 13, 15)
Sala Machine Works Ltd., (4, 12)

Sperry Vickers Div , Sperry Rand Corp , (3, 4, 8, 9, 10, 13, 15)
Spraying Systems Co , (3, 4, 5)
Sprout Waldron, Koppers Co , Inc , (1)
Templeton, Kenly & Co , (3, 4, 15)
Thomas Foundries Inc (3)
TRW Mission Mfg Co , Div of TRW Inc , (3)
Union Carbide Corp (3, 4, 10, 15)
Uniroyal, Inc , (12)
United States Steel Corp , (3, 6, 7, 10)
Varian Associates, (7)
Victaulic Co of America (1, 9, 13)
WABCO Fluid Power Div , an American Standard Co , (1, 3, 4, 5, 6, 10, 15)
Ward Hydraulics Div , ATO Corp , (3, 4)
Weatherhead Co , The (1, 13)
West Virginia Belt Sales & Repairs Inc , (8, 12)
Western Precipitation Div , Joy Mfg Co , (1, 9)
Workman Developments, Inc

WASHABILITY TESTS

Commercial Testing & Engineering Co
GEOMIN
Unifloc Limited

WASHERS, COAL

(SEE ALSO FLOTATION & TABLES, AIR)

1 CALCIUM-CHLORIDE
2 CYCLONE, HEAVY MEDIUM
3 CYCLONE, WATER
4 HEAVY MEDIUM
5 HYDROSEPARATOR
6 JIG
7 LAUNDERS, TROUGH
8 FLOTATION
9 TABLE-TYPE
10 UPWARD-CURRENT

ASV Engineering Ltd , (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Barber Greene Co , (4)
Daniels Company, The, (4, 8, 9)
Deister Concentrator Co Inc , The, (9)
Dorr Oliver Long, Ltd , (2, 3, 5)
Eagle Iron Works, (3, 4, 6)
Eriez Magnetics, (4)
FMC Corp , Agricultural Machinery Div
FMC Corp , Link-Belt Material Handling Systems Div , (4, 6)
Fairmont Supply Co , (4, 5, 6, 8)
Galigher Co , The, (8)
Garland Mfg Co , (6)
GEOMIN, (1, 2, 3, 4, 5, 6, 7, 8, 9, 10)
Head Wrightson & Co Ltd , (2, 3, 4, 5, 6, 7, 8)
Heyl & Patterson, Inc , (2, 3, 4, 8)
Irvin-McKelvy Co , The, (4)
Jeffrey Mfg Div , Dresser Industries Inc , (4, 5, 6, 8)
Jenkins of Retford Ltd , (2, 3, 4, 6, 8, 9)
Joy Mfg Co , Denver Equipment Div
KHD Industrieanlagen AG, Humboldt Wedag (4, 6, 8)
Kaiser Engineers, Inc
Krebs Engineers, (2, 3)
Linatex Corp of America (3)
Lively Mfg & Equipment Co , (2, 3, 4, 6, 8, 9, 10)
McNally Pittsburg Mfg Corp , (2, 3, 4, 6)
Mineral Services Inc , (2, 3)
Minerals Processing Co , Div of Trojan Steel Co (1, 4, 8, 9, 10)
Mintec International, Div of Barber Greene (4)
Ore Reclamation Co , (6)
Process Equipment, Stansteel Corp (3)
Roller Corp , (4, 9)
Sala International (2, 3, 8, 9)
Unifloc Limited
WEMCO Div , Envirotech Corp , (2, 3, 4, 5, 8, 10)
Wilmot Engineering Co (2, 4, 5, 6, 8, 10)
Workman Developments, Inc , (7)

VIBRATION ABSORBERS, DAMPERS

Cincinnati Rubber Mfg Co , Div of Stewart Warner Corp
Fabreeka Products Co
Firestone Tire & Rubber Co
GAF Corp
Goodall Rubber Co
Industrial Rubber Products Co
3 M Co
RKL Controls
Red Valve Co , Inc
Trelleborg Rubber Co , Inc
Uniroyal, Inc
Victaulic Co of America
Wichita Clutch Co , Inc
Workman Developments, Inc

VIBRATORS

1 BIN & HOPPER, CHUTE
2 R R HOPPER CAR

Aldon Company, The (2)
Branford Vibrator Co , The, Div of Electro Mechanics Inc , (1, 2)
Carman Industries, Inc , (1)
Dover Conveyor & Equipment Co , Inc , (1)
Eriez Magnetics (1)
FMC Corp , Material Handling Equipment Div (1, 2)
GEC Mechanical Handling Ltd (1)
Industrial Rubber Products Co (1, 2)
Jeffrey Mfg Div , Dresser Industries Inc , (1)
Martin Engrg Co , (1, 2)
National Air Vibrator Co , (1, 2)
Preiser/Mineco Div , Preiser Scientific Inc (1, 2)
Solids Flow Control Corp , (1)
Vibco Inc , (1, 2)
Vibranetics, Inc , (1, 2)
Vibra Screw Inc , (1)
West Virginia Belt Sales & Repairs Inc , (1)
Wichita Clutch Co , Inc , (1, 2)
Wilson, R M , Co (1)

WATER-CLARIFICATION & RECLAMATION SYSTEMS

American Cyanamid Co , Industrial Chemicals & Plastics Div
BIF, a unit of General Signal
Bird Machine Co , Inc
Calgon Corp
Carus Chemical Co
Crane Co
Daniels Company, The
Davis Instrument Mfg Co
Dorr Oliver Inc
Dorr Oliver Long, Ltd
Dravo Corp
du Pont de Nemours, E I & Co Inc
Envirex Inc
Environmental Equip Div , FMC Corp
Envirotech Corp , Eimco BSP Div
Eriez Magnetics
Ferro-Tech Inc
Hendrick Mfg Co
Heyl & Patterson, Inc
Holley, Kenney, Schott Inc
Industrial Contracting of Fairmont, Inc
Industrial Pneumatic Systems, Sub of Industrial Contracting of Fairmont, Inc
Jenkins of Retford Ltd
Joy Mfg Co , Denver Equipment Div
Kaiser Engineers, Inc
Koppers Co , Inc
Lively Mfg & Equipment Co
Loftus, Peter F , Corp
McNally Pittsburg Mfg Corp
Nalco Chemical Co
NUS Corp , Robinson & Robinson Div
Parkson Corp
Rexnord Inc
Rohm and Haas Co
Sala International
Stearns-Roger Inc
Treadwell Corp
Unifloc Limited
Westinghouse Electric Corp

WATER REPELLENTS

Anixter Mine & Smelter Supply
Cabot, Samuel, Inc
Dow Corning Corp
du Pont de Nemours, E I & Co Inc
3 M Co
Preiser/Mineco Div , Preiser Scientific Inc

WATER DEMINERALIZERS, SOFTENERS, TREATERS

Adams Equipment Co , Inc
Betz Laboratories
Calgon Corp
Capital Controls Co
Clayton Mfg Co
Crane Co
du Pont de Nemours, E I & Co Inc
Fisher Scientific Co
GAF Corp
Johnson Div , Universal Oil Products
Monsanto Co
PPG Industries, Inc , Chemical Div
Preiser/Mineco Div , Preiser Scientific Inc
Rexnord Inc
Rohm and Haas Co
Shirley Machine Co , Div Tasa Corp
Westinghouse Electric Corp
Wiegand, Edwin L , Div , Emerson Elec Co

WEAR PLATE, STRIPS

Ampco Metal Div , Ampco-Pittsburgh Corp
Asbury Industries, Inc
Carborundum Company
International Alloy Steel Div , Curtis Noll Corp
Manganese Steel Forge, Taylor Wharton Co , Div of Harsco Corp
N L Industries, Bearings Div
Poly Hi, Inc
Shwayder Co
Somerset Welding & Steel Inc
Stellite Div , Cabot Corp
Tool Steel Gear & Pinion Co
Workman Developments, Inc

WIRE CLOTH

Belleville Wire Cloth Co , Inc
Bonded Scale & Machine Co
Buffalo Wire Works Co , Inc
CE Tyler Inc
Cleveland Wire Cloth & Mfg Co
Durex Products, Inc , Natl Wire Cloth Div
Greening Donald Co Ltd
Hoyt Wire Cloth Co
Iowa Manufacturing Co
Keystone Steel & Wire Div of Keystone Consolidated Industries, Inc
Ludlow Saylor Wire Cloth Div G S I
Midwestern Industries, Inc , Screen Heating Transformers Div
Redding Co , James A
Simplicity Engineering
Smico Corp
SWECO Inc
West Virginia Belt Sales & Repairs Inc
Wilson, R M , Co
Wire Cloth Enterprises, Inc

Directory of Manufacturers

Bullet preceding (•) manufacturer indicates a products-information advertisement in this issue. See the advertisers index on the second to last page of this issue for the page number or numbers of the advertisement(s).

A

● ACF Industries, Inc., 2300 3rd Ave., P.O. Box 547, Huntington, W Va., 25710
A C R Equipment Co Inc., Parts Div., 19615 Nottingham Rd., Cleveland, Ohio, 44110
A & K Railroad Materials, Inc., P.O. Box 1276, Freeport Center, Clearfield, Utah, 84016
● ALPS Wire Rope Corp., 2350 Lunt Ave., Elkgrove Village, Ill., 60007
AMF Inc., 777 Westchester Ave., White Plains, N.Y., 10604
AMP Special Industries, Div. of AMP Products Corp., Valley Forge, Pa., 19482
AO Safety Products, Div. of Amer. Optical Corp., 14 Mechanic St., Southbridge, Mass., 01550
A-S-H Pump, Div. of Envirotech Corp., P. O. Box 635, Pack, Pa., 19301
ASV Engineering Ltd., Green Roof, York Rd., Doncaster, England, DN5 8HH
● Abex Corp., Denison Div., 1160 Dublin Rd., Columbus, Ohio, 43216
Abex Corp., Friction Products Group, 1650 W. Big Beaver, Troy, Mich., 48084
Abex Corp., Railroad Products Group, 530 Fifth Ave., New York, N.Y., 10036
Acco Allison Campbell Div., 875 Bridgeport Ave., Shelton, Conn., 06484
Acco American Chain Div., 454 E. Princess St., York, Pa., 17403
Acco, Bristol Div., Box 1790, Waterbury, Conn., 06720
Acco, Cable Controls Div., 1022 E. Michigan St., Adrian, Mich., 49221
Acco, Crane & Monorail Systems Div., Box 140, Fairfield, Iowa, 52556
Acco, Electro-Mech Div., 1 Research Dr., Stratford, Conn., 06497
Acco, Helicoid Gage Div., 929 Connecticut Ave., Bridgeport, Conn., 06602
Acco, Hoist & Crane Div., P. O. Box 792, York, Pa., 17405
Acco, Integrated Handling Systems Div., Bailes Rd., Frederick, Md., 21701
Acco, Malleable Casting Div., 1100 E. Princess St., York, Pa., 17403
Acco Mining Sales Div., P. O. Box 15537, Pittsburgh, Pa., 15244
Acco, Page Fence Div., First & River Sts., Monessen, Pa., 15062
Acco, Page Welding Div., P. O. Box 976, Bowling Green, Ky., 42101
Acco, Unit Conveyor Div., 10601 W. Belmont Ave., Franklin Park, Ill., 60131
● Acker Drill Co., Inc., P. O. Box 830, Scranton, Pa., 18501
Acme-Hamilton Mfg. Corp., Belting Div., E. State St., P. O. Box 361, Trenton, N. J., 08603
Acme Machinery Co., Box 2409, Huntington, W. Va., 25725
● Acrow Corp. of America, 396 Washington Ave., Carlstadt, N. J., 07072
Adams Equipment Co., Inc., 8421 25 Wabash, St. Louis, MO, 63134
Adhesive Engineering Co., 1411 Industrial Rd., San Carlos, Calif., 94070.
Advance Car Mover Co., Inc., 112 N. Outagamie St., P.O. Box 1181, Appleton, Wis., 54911
Advanced Mining & Mfg. Co., P. O. Box 9387, Huntington, W. Va., 25701
Aerial Map Service Co., 1016 Madison Ave., Pittsburgh, Pa., 15212
Aerial Surveys, Inc., 4614 Prospect Ave., Cleveland, Ohio, 44103
Aerofall Mills Ltd., 2640 So. Sheridan Way, Mississauga, Ont., Canada, L5J 2M4
Aeroquip Corp., 300 S. East Ave., Jackson, Mich., 49203
Aero Service Div., Western Geophysical Co. of Amer., P.O. Box 1939, Houston, TX, 77001
Aggregates Equipment Inc., 9 Horseshoe Rd., Leola, Pa., 17540
Air Correction Div., UOP, Box 1107, Darien, Conn., 06820
Air-Lert, Inc., P. O. Box 342, Proctorville, OH, 45669
Air Pollution Control Operations, FMC Corp., 799 Roosevelt Rd., Glen Ellyn, Ill., 60137
Aitken Products, Inc., P.O. Box 151, Geneva, Ohio, 44041
Alabama State Docks, P.O. Box 1588, Mobile, Ala., 36601
Albright Mfg. Co., Inc., 7232 N. Western Ave., Chicago, Ill., 60645
Alcoa, 1501 Alcoa Bldg., Pittsburgh, Pa., 15219
Alcoa Conductor Products Co., Div. Aluminum Co. of America, 510 One Allegheny Sq., Pittsburgh, Pa., 15212
Alcolac, Inc., 3440 Fairfield Rd., Baltimore, Md., 21226
Aldon Company, The, 3410 Sunset Ave., Waukegan, Ill., 60085
Alemite & Instrument Div., Stewart-Warner Corp., 1826 Diversey Pkwy., Chicago, Ill., 60614
Allegheny Ludlum Steel Corp., 2420 Oliver Bldg., Pittsburgh, Pa., 15222
Allen-Bradley Co., 1201 S. Second St., Milwaukee, Wis., 53204
Allen & Garcia Co., 332 S. Michigan Ave., Chicago, Ill., 60604
Allentown Pneumatic Gun Co., P. O. Box 185, Allentown, Pa., 18105
Allied Chemical Corp., Industrial Chemicals Div., P.O. Box 1139R, Morristown, N. J., 07960
Allied Steel & Tractor Products, Inc., 5800 Harper Rd., Solon, Ohio, 44139
● Allis-Chalmers, P.O. Box 512, 1125 S. 70th St., Milwaukee, Wis., 53201
Allis-Chalmers, Crushing & Screening Equipment, P.O. Box 2219, Appleton, WI 54911
Allmand Bros., Inc., W. Highway 23, Holdrege, Neb., 68949
ALMEG, P.O. Box 11430, Kansas City, Mo., 64112
Alnor Instrument Co., 7301 N. Caldwell Ave., Niles, Ill., 60648
Alpine Equipment Corp., P.O. Box 106, 140 N. Gill St., State College, Pa., 16801
Alten Speed Reducer Div., Alten Foundry & Machine Works, Inc., P. O. Box 550, Lancaster, Ohio, 43130
● American Air Filter Co., Inc., P.O. Box 1100, Louisville, Ky., 40201
American Alloy Corp., Pyramid Parts Div., 3000 E. 87th St., Cleveland, OH, 44104
American Alloy Steel, Inc., 2070 Steel Dr., Tucker, GA, 30084
● American Commercial Barge Line Co., P. O. Box 610, Jeffersonville, Ind., 47130
American Crucible Products Co., 1305 Oberlin Ave., Lorain, Ohio, 44052
American Cyanamid Co., Industrial Chemicals & Plastics Div., Berdan Ave., Wayne, N. J., 07470
American Hoist & Derrick Co., 63 South Robert St., St. Paul, Minn., 55107
American Industrial Leasing Co., 201 N. Wells St., Chicago, Ill., 60601
American Logging Tool Corp., 302 N. Main St., Evart, Mich., 49631
American Meter Div., Singer Co., The, 13500 Philmont Ave., Philadelphia, PA, 19116
American Minechem Corp., P.O. Box 231, Coraopolis, Pa., 15108
● American Mine Door Co., Box 6028, Station B, Canton, Ohio, 44706
American Mine Supply Co., 404 Frick Bldg., Pittsburgh, Pa., 15219
American Optical Corp., 14 Mechanic St., Southbridge, Mass., 01550
● American Poclain Corp., 3401 Tidewater Trail, Fredericksburg, VA 22401
● American Pulverizer Co., 1249 Macklind Avenue, St. Louis, Mo., 63110
American Rectifier Corp., 15th Ave., College Point, N.Y., 11356
American Standard Industrial Products Div., 8111 Tireman Ave., Dearborn, Mich., 48126
● American Tractor Equip. Co., P.O. Box 1226, Oakland, Calif., 94604
American VM, Inc., 256 Welsh Pool Rd., Lionville, Pa., 19353
Amerind-MacKissic, Inc., Box 111, Parker Ford, Pa., 19457
Ametek, East Moline, Ill., 61244
Amoco Oil Company, 200 E. Randolph Dr., Chicago, Ill. 60601
Ampco Metal Div., Ampco-Pittsburgh Corp., P.O. Box 2004, Dept. 1723, Milwaukee, Wis., 53201
● Amsco Div., Abex Corp., 389 E. 14th St., Chicago Heights, Ill., 60411
● Anaconda Company, Wire and Cable Div., Greenwich Office Park 3, Greenwich, Conn., 06830
Analytical Measurements, Inc., 31 Willow St., Chatham, N.J., 07928
Anchor Conveyors Div., Standard Alliance Indus., Inc., 6906 Kingsley Ave., P.O. Box 650, Dearborn, MI, 48121
Anchor Coupling Co., Inc., 342 N. Fourth St., Libertyville, Ill., 60048
Anchor/Darling Valve Co., 24747 Clawiter Rd., Hayward, CA, 94545
Anderson Electric Corp., Box 455, Leeds, Ala., 35094
Anderson Mavor (USA) Ltd., 301 Progress St., Cranberry Ind. Park, Zelienople, Pa., 16063
Anderson Power Products, Inc., 145 Newton St., Boston, Mass., 02135
Anixter Bros., 4711 Golf Rd., Skokie, Ill., 60076
Anixter Mine & Smelter Supply, 5040 E. 41st St., Denver, Colo., 80216
Ansul Co., The, 1 Stanton St., Marinette, Wis., 54143
Apache Powder Co., P.O. Box 700, Benson, Ariz., 85602
Applied Science, Box 158, Valencia, Pa., 16059
Aquadyne, Div. of Molymco, Inc., 267 Vreeland Ave., Paterson, N. J., 07513
● Armco Steel Corp., Product Info., 703 Curtis St., Middletown, Ohio, 45043
● Armstrong, Bray & Co., 5366 Northwest Hwy., Chicago, Ill., 60630
Armstrong Bros. Tool Co., 5200 W. Armstrong Ave., Chicago, Ill., 60646
● Aro Corp., The, One Aro Center, Bryan, Ohio, 43506
Artograph Inc., 529 S. 7th St., Minneapolis, Minn., 55415
Asbury Industries, Inc., 4351 William Penn Hwy., Murrysville, Pa., 15668
ASEA Inc., 4 New King St., White Plains, N.Y., 10604
Ashland Chemical Co., P. O. Box 2219, Columbus, Ohio, 43216
Ashland Oil & Refining Co., P. O. Box 391, Ashland, Ky., 41101
Associated Research Inc., 6125 W. Howard St., Chicago, Ill., 60648
Astrosystems, Inc., 6 Nevada Dr., Lake Success, NY, 11040
Athey Products Corp., P. O. Box 669, Raleigh, N. C., 27602
Atkinson Armature Works, 116 E. 1st St., Pittsburg, Kan., 66762
Atkinson Dynamics, 10 West Orange Ave., So. San Francisco, Calif., 94080
● Atlantic Mobile Corp., 111 Chesapeake Park Plaza, Baltimore, Md., 21220
Atlantic Track & Turnout Co., 270 Broad St., Bloomfield, N.J., 07003
Atlas Bolt & Screw Co., Atlas Car & Mfg. Div., 1100 Ivanhoe Rd., Cleveland, Ohio, 44110
Atlas Copco, Inc., 70 Demarest Dr., Wayne, N. J.
Atlas Powder Co., 12700 Park Central Pl., Ste. 1700, Dallas, TX, 75230
Atlas Railroad Construction Co., P.O. Box 8, Eighty Four, Pa., 15330
A T O Inc., 4420 Sherwin Rd., Willoughby, Ohio, 44094
Aurora Pump, Unit of General Signal, 800 Airport Rd., N. Aurora, Ill., 60542
Austin, J. P., Inc., 300 Mt. Lebanon Blvd., Pittsburgh, Pa., 15234
● Austin Powder Co., 3735 Green Rd., Cleveland, Ohio, 44122
Austin-Western Div., Clark Equipment Co., 601 N. Farnsworth Ave., Aurora, Ill., 60507
Auto Crane Co., 9260 Broken Arrow Expressway, P.O. Box 45548, Tulsa, Okla., 74145
Auto Weigh Inc., P.O. Box 4017, 1439 N. Emerald Ave., Modesto, Cal., 95352
Automatic Sprinkler Corp., P.O. Box 180, Cleveland, Ohio, 44147
Automatic Vulcanizers Corp., 555 Madison Ave., New York, N.Y., 10022
Automation Products, Inc., 3030 Max Roy St., Houston, Texas, 77008

B

Babcock & Wilcox, 161 East 42nd St., New York, N.Y., 10017
Bacharach Instrument Co., Mining Div., 625 Alpha Dr., R.I.D.C. Industrial Park, Pittsburgh, Pa., 15238
Bache & Co., Inc., Box 400, Wall Street Station, New York, N.Y., 10005
Badall Co., Inc., 4902 Calumet Ave., Hammond, Ind., 46327
Badger Construction Co., Div. of Mellon-Stuart Co., 1925 Beaver Ave., Pittsburgh, Pa., 15233
Badger Mfg. Corp., 818 Main St., Summersville, WV, 26651
Balderson Inc., Box 6, Wamego, Kan., 66547
Baldwin Belting Inc., 286-288 Spring St., New York, N.Y., 10013
Baltimore & Ohio R.R. Co., 1 Charles Center, 21st Fl., Baltimore, Md., 21201
Banks-Miller Supply Co., P.O. Box 2111, Huntington, W.Va., 25706
Banner Bearings, P.O. Box 6040, Stonewall Station, Charleston, W.Va., 25302
Bantam Div., Koehring Co., 201 Park St., Waverly, Iowa, 50677
Barber-Greene Co., 400 N. Highland Ave., Aurora, Ill., 60507
Barber Manufacturing Co., Radac Div., 22901 Aurora Rd., Bedford Hts., Ohio, 44146
Barksdale Controls Div./DELAVAL Turbine Inc., 5125 Alcoa Ave., Los Angeles, Calif., 90058
Barnes Engineering Co., 30 Commerce Rd., Stamford, Conn., 06904
Barnes & Reinecke, Inc., 2375 Estes Ave., Elk Grove Village, Ill., 60007
Barrett, Haentjens Co., Box 488, Hazelton, Pa., 18201
Batteries Inc., Box 275, Sprague, W.Va., 25926
BASF Wyandotte Corp., Wyandotte, Mich., 48192
Bausch & Lomb, SOPD Div., 80476 Bausch St., Rochester, N.Y., 14602
Bear Mfg. Corp., 2830 5th St., Rock Island, Ill., 61201
Bearcat Tire Co., 5201 W. 65th St., Chicago, Ill., 60638
Bearing Service Co., 500 Dargan St., Pittsburgh, Pa., 15224
● Bearings, Inc., 3600 Euclid Ave., Cleveland, Ohio, 44115
Beaumont, Edward C., 3236 Candelaria Rd., N.E., Albuquerque, N.M., 87107
Beckman Instruments, Inc., 2500 Harbor Blvd., Fullerton, Calif., 92634
Beebe Bros., Inc., 2724 Sixth Ave. S., Seattle, Wash., 98006
Bekaert Steel Wire Corp., 245 Park Ave., New York, N.Y., 10017
Bellefonte Insurance Cos., Sub. of Armco Steel Corp., 703 Curtis St., Middletown, OH, 45043
Belleville Wire Cloth Co., Inc., 135 Little St., Belleville, N.J., 07109
● Bell Helicopter Co., P.O. Box 482, Fort Worth, Texas, 76101
Bemis Co., Inc., 800 Northstar Center, Box 84A, Minneapolis, Minn., 55402
Berger Associates, Ltd., P.O. Box 2116, Columbus, Ohio, 43216
Bessemer & Lake Erie R.R., P.O. Box 536, Pittsburgh, Pa., 15230
Bete Fog Nozzle, Inc., 305 Wells St., Greenfield, Mass., 01301
Bethlehem Steel Corp., Martin Tower, Bethlehem, Pa., 18016
Betz Laboratories, 4636 Somerton Rd., Trevose, Pa., 19047
BICC Limited, P.O. Box No. 5, 21 Bloomsbury St., London WC1B 3QN, England
BIF, a unit of General Signal, 1600 Division Rd., West Warwick, R.I., 02893
Biach Industries Inc., P.O. Box 337 L, Cranford, N.J., 07016
Biddle Co., James G., Township Line & Jolly Rds., Plymouth Meeting, Pa., 19462
● Big Noise Instruments, Div. of Improvecon Corp., 25 Sylvan Rd., So. Westport, Conn., 06880
Big Sandy Electric & Supply Co., Inc., P.O. Box 2099, South US 23, Pikeville, Ky., 41501
Bigelow-Liptak Corp., 21201 Civic Center Dr., Southfield, Mich., 48076
Bindicator Co., Div. of Improvecon Corp., 1915 Dove St., Port Huron, Mich., 48060
● Bird Machine Co., Inc., Neponset St., South Walpole, Mass., 02071
Birdsboro Corp., Birdsboro, PA, 19508
Bixby-Zimmer Engrg. Co., 961 Abingdon St., Galesburg, Ill., 61401
Blair Mine Supply Inc., P.O. Box 2182, Clarksburg, W.Va., 26301
Blaw-Knox Equipment, Inc., P.O. Box 11450, Pittsburgh, Pa., 15238
Bofors America, Inc., 1075 Edward St., Linden, N.J., 07036
Boggess, B.L., Co., Mine Development Group, 801 Grant St., Denver, Colo., 80203
Bonded Scale & Machine Co., 2176 So. Third St., Columbus, Ohio, 43207
Boston Industrial Products Div., American Biltrite Inc., P.O. Box 1071, Boston, Mass., 02103
Boston Insulated Wire & Cable Co., Bay St., Boston, Mass., 02125
Bostrom Div., UOP Inc., 133 W. Oregon St., Milwaukee, Wisc., 53201
● Bowdil Co., Box 470, 1018 Boylan Ave., S.E., Canton, Ohio, 44701
Bowman Distribution, Barnes Group, Inc., 850 E. 72nd St., Cleveland, Ohio, 44103
Boyd, John T. Co., Oliver Bldg., Pittsburgh, Pa., 15222
Boyles Bros. Drilling Co., P.O. Box 58, Salt Lake City, UT, 84110
Brad Harrison Co., 600 E. Plainfield Rd., LaGrange, Ill., 60525
Branford Vibrator Co., The, Div. of Electro-Mechanics, Inc., 150 John Downey Dr., New Britain, Conn., 06051
Bridgestone Tire Co. of America, Inc., 2160 W. 190 St., Torrance, Cal., 90509
Bridgestone Tire Co., Ltd., 1-1-chome, Kyobashi, Chuo-ku, Tokyo, Japan
● Bridon American Corp., Box 188, W. Pittston, Pa., 18643
British Jeffrey Diamond, Div. of Dresser Europe S.A. (U.K. Branch), Thornes Works, Wakefield, W. Yorks, England
Broderick & Bascom Rope Co., 10440 Trenton Ave., St. Louis, Mo., 63132
Brookville Locomotive Div., Pennbro Corp., Steel Blvd., Brookville, Pa., 15825
Brown Mining Construction Co., P.O. Box 1589, Fairmont, W.Va., 26554
Browning Mfg. Div., Emerson Electric Co., Box 687, Maysville, Ky., 41056
Bruening Bearings, Inc., 3600 Euclid Ave., Cleveland, Ohio, 44115
Bruning Co., P.O. Box 81247, Lincoln, Neb., 68501
Brunner & Lay, Inc., 9300 King St., Franklin Park, Ill., 60131
Brush Transformers Ltd., P.O. Box 70, Loughborough, Leicestershire, England, LE11 1HH
Bucyrus Blades, Inc., 260 E. Beal Ave., Bucyrus, OH, 44820
Bucyrus-Erie Co., P.O. Box 56, S. Milwaukee, Wis., 53172
Budd Co., Plastic Products Div., Polychem Products, Franklin Ave. & Grant Sts., Phoenixville, PA, 19460
Buffalo Wire Works Co., Inc., P.O. Box 129, Buffalo, NY, 14240
Bullard, E. D. Co., 2680 Bridgeway, Sausalito, Calif., 94965
Bussmann Mfg. Div., McGraw-Edison Co., University at Jefferson, St. Louis, Mo., 63107
Byron Jackson Pump Div., Borg Warner Corp., P.O. Box 2017, Terminal Annex, Los Angeles, Calif., 90051

C

CCS Hatfield Mining Products, 12 Commerce Dr., Cranford, N.J., 07016
● C & D Batteries, Div. of ELTRA Corp., 3043 Walton Rd., Plymouth Meeting, Pa., 19462
CE Ehrsam, 300 N. Cedar, Abilene, Kan., 67410
C-E Power Systems, Combustion Eng., Inc., 1000 Prospect Hill Rd., Windsor, Conn., 06095
C E Raymond/Bartlett Snow, Div. Combustion Engineering, Inc., 427 W. Randolph St., Chicago, Ill., 60606
CE Tyler Inc., 8200 Tyler Blvd., Mentor, Ohio, 44060
C F & I Steel Corp., P.O. Box 1830, Pueblo, Colo., 81002
CM Chain Div., Columbus McKinnon Corp., Fremont St., Tonawanda, N.Y., 14150
CMI Corp., P.O. Box 1985, Oklahoma City, OK, 73101
CR Industries, Chicago Rawhide, 2720 N. Greenview Ave., Chicago, Ill., 60614
CRC Kelley Products, an Oper. of Crutcher Resources Corp., P.O. Box 3227, Houston, Texas, 77001
● CSE Mine Service Co., 2000 Lido Rd., Monroeville, Pa., 15146
Cable Belt Conveyors Inc., 350 Fifth Ave., New York, N.Y., 10001
Cabot, Samuel, Inc., One Union St., Boston, Mass., 02108
Calgon Corp., P.O. Box 1346, Pittsburgh, Pa., 15230
Caliper Corp., Industrial Mktg. Div., 200 Stauffer, Naperville, Ill., 60540
Call, Inc., Ray C., P.O. Box 8245, So. Charleston, W.Va., 25303
Calweld, Div. of Smith International, Inc., P.O. Box 2875, 9200 Sorensen Ave., Santa Fe Springs, Calif., 90670
Calwis Co., P.O. Box 3743, Green Bay, Wi., 54303
Cam-Lok Div., Empire Products, Inc., 10540 Chester Rd., Cincinnati, Ohio, 45215
Campbell, E. R. Co., 1809 Manchester Trafficway, Kansas City, Mo., 64126
Campbell Chain Co., P.O. Box 3052, York, Pa., 17402
CAM RAL Chain Co., Inc., 450 Ragland Rd., Beckley, W.Va., 25801
Canton Stoker Corp., P.O. Box 6058, Canton, Ohio, 44706
Capital City Industrial Supply Co., 544 Broad St., Charleston, W.Va., 25323
Capital Conservation Group, Fifth Ave. E. & 18th St., Hibbing, Minn., 55746
Capital Controls Co., 201 Advance Lane, P.O. Box 211, Colmar, PA, 18915
● Carborundum Company, P.O. Box 367, Niagara Falls, N.Y., 14302
Card Corp., P.O. Box 117, Denver, Colo., 80201
Cardinal Scale Mfg. Co., 203 E. Daugherty, Webb City, Mo., 64870
● Carman Industries, Inc., 1005 W. Riverside Dr., Jeffersonville, Ind., 47130
● Carmet Co., Minetool Div., P.O. Box 127, Shinnston, W.Va., 26431
● Carol Cable Co., Div. of Avnet, Inc., 249 Roosevelt Ave., Pawtucket, R.I., 02862
Carver Pump Co., 1056 Hershey Ave., Muscatine, Iowa, 52761
Carus Chemical Co., 1500 8th St., LaSalle, IL, 61301
Case, J.I., Co., C.E. Div., 700 State St., Racine, Wis., 53404
Cashco, Inc., 540 N. 18th St., Decatur, Ill., 62525
Catalytic, Inc., 1500 Market St., Centre Square West, Philadelphia, PA, 19102
● Caterpillar Tractor Co., 100 N.E. Adams, Peoria, Ill., 61629
Celanese Chemical Co., 1211 Ave. of the Americas, New York, N.Y., 10036
● Celanese Fibers Marketing Co., 1211 Ave. of Americas, New York, N.Y., 10036
Cellite, Inc., 13670 York Rd., Cleveland, Ohio, 44133
Cementation Co. of America, Inc., P.O. Box 9, Brampton, Ont., Canada, L6V 2K7
Cementation Mining Ltd., Bentley Works, Bentley, Doncaster, England, DN5 0BT
Central Engineering Co., Inc., 4429 W. State St., Milwaukee, Wis., 53208
Central Mine Equipment Co., 6200 N. Broadway, St. Louis, Mo., 63147
Central States Industries, Inc., Mining Products Div., Terminal Tower, Cleveland, Ohio, 44113
● Centrifugal & Mechanical Industries, Inc., 146 President St., St. Louis, Mo., 63118
Cerro Wire & Cable Co., Div. of Cerro-Marmon Corp., Nicoll and Canner Sts., New Haven, Conn., 06504
Cerro Wire & Cable Co. (Maspeth), 5500 Maspeth Ave., Maspeth, N.Y., 11378
● Certain-Teed Products Corp., Pipe & Plastics Group, Box 860, Valley Forge, Pa., 19482
Certified Welding Services Inc., Drawer F, Stanaford, W.Va., 25927
Chain Systems, Div. of R. H. Carter & Co., Inc., P.O. Box 126, Springfield, Va., 22150
Challenge-Cook Bros., Inc., 15421 E. Gale Ave., Industry, Calif., 91745
Cheatham Elec. Switching Device Co., 4780 Crittenden Dr., Louisville, Ky., 40221
Chemetron Corp., 111 E. Wacker Dr., Chicago, Ill., 60601
Chemetron Corp., Welding Products, 111 E. Wacker Dr., Chicago, Ill., 60601
Chesterton, A.W., Company, Middlesex Industrial Park, Rt. 93, Stoneham, Mass., 02180
Chicago Pneumatic Equipment Co., 191 Howard St., Franklin, Pa., 16323
Christensen Diamond Products, P.O. Box 387, 1937 S. 3rd W., Salt Lake City, Utah, 84110
● Chromalloy, Shore-Mack Div., 1460 Auto Ave., P.O. Box 431, Bucyrus, Ohio, 44820
● CIBA-GEIGY Corp., Pipe Systems Dept., 9800 Northwest Freeway, Suite 201, Houston, Texas, 77018
● Cincinnati Mine Machinery Co., 2980 Spring Grove Ave., Cincinnati, Ohio, 45225
● Cincinnati Rubber Mfg. Co., Div. of Stewart-Warner Corp., 4900 Franklin Ave., Cincinnati, Ohio, 45212
Cisco Fabricating Co., P.O. Box 75, Carlinville, Ill., 62626
● CIT Corp., 650 Madison Ave., New York, N.Y., 10022
● Citizens Fidelity Bank & Trust Co., Citizens Plaza, Louisville, Ky., 40202
Clark Equipment Co., Axle & Transmission Divs., 324 Dewey St., Buchanan, Mich., 49107
● Clark Equipment Co., Construction Machinery Div., P.O. Box 547, Benton Harbor, Mich., 49022
Clark Equipment Co., Lima Div., 1046 S. Main St., Lima, Ohio, 45802
Clark Equipment Co., Melroe Div., 112 N. University Dr., Fargo, N.D., 58102
Clarkson Co., 735 Loma Verde Ave., Palo Alto, Calif., 94303
Clayton Mfg. Co., P.O. Box 5530, El Monte, Calif., 91734
Clayton Mark-Pacific Valves, Div. of Mark Controls Corp., 1900 Dempster St., Evanston, IL, 60204
Cleveland Armstrong Corp., 1108 S. Kilbourn St., Chicago, Ill., 60624
Cleveland Wire Cloth & Mfg. Co., 3573 E. 78th St., Cleveland, Ohio, 44105
Coeur d'Alenes Co., Bldg. #7, Industrial Park, Spokane, Wash., 99216
Coffing Hoist Div., Duff-Norton Co., P.O. Box 1719, Charlotte, N.C., 28232
Collins Radio, 400 Collins Rd., N.E., Cedar Rapids, IA, 52406
Collyer Insulated Wire Co., 100 Higginson Ave., Lincoln, R.I., 02865
Colt Industries, Crucible, P.O. Box 226, Midland, Pa., 15059
Columbia Steel Casting Co., Inc., 10425 N. Bloss Ave., Portland, Ore., 97203
Combustion Equipment Associates, Inc., 555 Madison Ave., New York, N.Y., 10022
● Commercial Shearing, Inc., 1775 Logan Ave., Youngstown, Ohio, 44501
Commercial Testing & Engineering Co., 228 N. La Salle St., Chicago, Ill., 60601
● Communication & Control Eng. Co. Ltd., Park Rd., Calverton, Nottingham, England
CompAir Construction & Mining Ltd., Camborne, Cornwall, England, TR14 8DS
Compton Electrical Equipment Corp., 720 15th St. W., Box 285, Huntington, WV, 25707
Computer Assistance Co., 505 Maple Lane, Sewickley, Pa., 15143
Concrete Equipment Co., Inc., P.O. Box 430, Blair, NE, 68008
Cone-Drive Gears, A Unit of Ex-Cell-O Corp., P.O. Box 272, Traverse City, Mich., 49684
Connecticut Hard Rubber Co., Sub. of Armco Steel Corp., Box 1911, New Haven, Conn., 06509
Connellsville Corp., 120 S. Third, Connellsville, Pa., 15425
Conners Steel Co., P.O. Box 118, Huntington, W.Va., 25706
Conrac Corp., 330 Madison Ave., New York, N.Y., 10017
Consolidated Railway Corp., 1542 Six Penn Center, Philadelphia, PA, 19103
● Continental Conveyor & Equipment Co., P.O. Box 400, Winfield, Ala., 35594
Continental Oil Co., P.O. Box 2197, Houston, Tex., 77001
Continental Rubber Works, Sub. of Continental Copper & Steel Industries, Inc., 2000 Liberty St., Erie, Pa., 16512
Contractors Warehouse Inc., 1600 No. Fort Myer Dr., Arlington, Va., 22209
Control Concepts, Terry Dr., Newton, PA, 18940
Control Products, Inc., P.O. Drawer 1087, Beckley, W.Va., 25801
Controlled Systems Inc., P.O. Box 175, Fairmont, W.Va., 26554
Conveyor Components Co., 3640 Milwaukee, Lakeport, Mich., 48060
Conwed Corp., Environmental Products Div., 2200 Highcrest Rd., St. Paul, MN, 55113
Co-Ordinated Industries, Rd. #2 Flaugherty Run Rd., Coraopolis, Pa., 15108
Coppinger Machinery Service, P.O. Box 89, Bluefield, W.Va., 24701
Corhart Refractories Co., Div. of Corning Glass Works, 1600 W. Lee St., Louisville, Ky., 40210
Costain Mining Ltd., 111 Westminster Bridge Rd., London, SE1 8EW, England
Crane Co., 300 Park Ave., New York, N.Y., 10022
● Crisafulli Pump Co., Inc., Box 1051, Glendive, Mont., 59330
Crosby Group, 2801 Dawson Road, P.O. 3128, Tulsa, Okla., 74101
Crouse-Hinds Co., Wolf & 7th North St., Syracuse, N.Y., 13201
Crown Iron Works Co., P.O. Box 1364, Minneapolis, Minn., 55440
Cummins Engine Co., Inc., 1000 5th St., Columbus, Ind., 47201
Curry Manufacturing Corp., P.O. Box 618, Glade Spring, Va., 24340
Cushman OMC-Lincoln, P.O. Box 82409, 1401 Cushman Dr., Lincoln, Neb., 68512
Cutler-Hammer, Inc., 4201 N. 27th St., Milwaukee, Wis., 53216
Cyclone Drill Co., Orrville, Ohio, 44667
● Cyclone Machine Corp., P.O. Box 39, Scott Depot, W.Va., 25560
Cypher Co., The, 1201 Washington Blvd., Pittsburgh, Pa., 15206
● Cyprus Wire & Cable Co., 421 Ridge St., Rome, N.Y., 13440

D

D A Lubricant Co., Inc., 1331 W. 29th St., Indianapolis, Ind., 46208
DAP Inc., 5300 Huberville Ave., P.O. Box 277, Dayton, Ohio, 45401
D P Way Corp., P.O. Box 09336, Milwaukee, Wisc., 53209
● Dana Corp., Spicer Universal Joint Div., P.O. Box 986, Toledo, Ohio, 43696
Daniels, C. R., Inc., 3451 Ellicott Center Dr., Ellicott City, Md., 21043
Daniels Company, The, Route 2, Box 203, Bluefield, W.Va., 24701
Dart Truck Company, P.O. Box 321, Kansas City, Mo., 64141
Darworth Co., Tower Lane, Avon, Conn., 06001
Davey Compressor Co., 11060 Kenwood Rd., Cincinnati, Ohio, 45242
● Davey Roussele, Drill Rig Div., 2310 W. 78th St., Chicago, Ill., 60620
Davis Instrument Mfg. Co., 517 E. 36th St., Baltimore, Md., 21218
Davis, J. J., Associates, Inc., 7900 Westpark Dr., Ste 915, McLean, Va., 22101
Davis, John & Son (Derby) Ltd., 20 Alfreton Rd., Derby, DE2 4AB, England
Dayco Corp., Rubber Products Div., 333 W. 1st St., Dayton, Ohio, 45402
Dayton Automatic Stoker Co., 111 Deeds Ave., P.O. Box 255, N. Dayton Station, Dayton, Ohio, 45404
Dean Brothers Pumps, Inc., P.O. Box 68172, Indianapolis, IN, 46268
Dean Witter & Co., Inc., 130 Liberty St., New York, N.Y., 10006
Deere & Co., John Deere Rd., Moline, IL, 61265
Deister Concentrator Co. Inc., The, 901 Glasgow Ave., Ft. Wayne, Ind., 46801

Deister Machine Co., Inc., P.O. Box 5188, Ft. Wayne, Ind., 46805
Delavan Electronics, Inc., 14605 North 73rd St., Scottsdale, Ariz., 85260
Delavan Mfg. Co., Grand Ave. & 4th St., West Des Moines, Iowa, 50265
Delta Wire & Cable Co., 1457 W. Diversey Pkwy., Chicago, Ill., 60614
DEMAG Lauchhammer, 7061 Warburg, Forststrasse 16, 4000 Dusseldorf 13, Fed. Rep. of Germany
Deron R & D Co., Inc., P.O. Box 603, Morgantown, W. Va., 26505
Derrick Mfg. Co., 580 Duke Rd., Buffalo, N.Y., 14225
DESA Industries, A Unit of AMCA Intl. Corp., 25000 S. Western Ave., Park Forest, Ill., 60466
● Detrick, M. H., Co., 20 N. Wacker Dr., Chicago, Ill., 60606
Detroit Diesel Allison Div., General Motors Corp., 13400 W. Outer Dr., Detroit, Mich., 48228
Deutz Corp., 7585 Ponce de Leon Cir., Atlanta, Ga., 30340
DeZurik, a Unit of General Signal, Sartell, MN, 56377
Diamond Chain Co., 402 Kentucky Ave., Indianapolis, Ind., 46225
Diamond Crystal Salt Co., 916 S. Riverside Ave., St. Clair, Mich., 48079
Diamond Tool Research Co., Inc., 345 Hudson St., New York, N.Y., 10014
Dick Inc., R. J., P.O. Box 306, King of Prussia, Pa., 19406
Dico Co., Inc., 200 S.W. 16th St., Des Moines, IA, 50305
Dilco, Inc., Box 238, Findlay, Ohio, 45840
Dings Co., Dynamics Group, 4742 W. Electric Ave., Milwaukee, Wis., 53219
Dings Co., Magnetic Group, 4742 W. Electric Ave., Milwaukee, Wis., 53219
Diversified Electronics, Inc., 119 N. Morton Ave., Evansville, Ind., 47711
Dixie Bearings, Inc., 3600 Euclid Ave., Cleveland, Ohio, 44115
Dixon Valve & Coupling Co., KRM Bldg., 800 High St., Chestertown, Md., 21620
Dodge Div., Reliance Electric Co., 500 So. Union St., Mishawaka, Ind., 46544
Dominion Engineering Works Ltd., P.O. Box 220, Montreal, Que., Canada, H3C 2S5
Donaldson Co., Inc., P.O. Box 1299 (1400 W. 94 St.), Minneapolis, Minn., 55440
Dorr-Oliver Inc., 77 Havemeyer La., Stamford, Conn., 06904
Dorr Oliver Long, Ltd., Orillia, Ontario, Canada
Dosco Corp., 740 Vista Park Dr., Pittsburgh, Pa., 15205
● Dover Conveyor & Equipment Co., Inc., Box 300, Midvale, OH, 44653
Dow Chemical Co., 2020 Abbott Rd. Center, Midland, Mich., 48640
Dow Corning Corp., Midland, Mich., 48640
● Dowell Div. of the Dow Chemical Co., P.O. Box 21, Tulsa, Okla., 74102
● Dowty Corp., Progress St., Cranberry Industrial Park, Zelienople, Pa., 16063
Dravo Corp., One Oliver Plaza, Pittsburgh, Pa., 15222
Dresser Industries, Inc., Crane & Hoist Operations, W. Broadway, Muskegon, Mich., 49443
Dresser Industries, Inc., Industrial Products Div., 900 W. Mount St., Connersville, Ind., 47331
Dresser Manufacturing, Div. Dresser Industries, Inc., 450 Fisher Ave., Bradford, Pa., 16701
Dresser Mining Services & Equipment Div., P.O. Box 24647, Dallas, Texas, 75224
Drill Systems Inc., P.O. Box 5140, Station "A", Calgary, Alberta, Canada, T2H 1X3
Ducon Co., Inc., The, 147 E. Second St., Mineola, N.Y., 11501
Duff-Norton Co., P.O. Box 1719, Charlotte, N.C., 28232
● du Pont de Nemours, E. I. & Co. Inc., 1007 Market St., Wilmington, Del., 19898
Duplex Mill & Mfg. Co., 415 Sigler St., Box 1266, Springfield, Ohio, 45501
Duquesne Mine Supply Co., 2 Cross St., Pittsburgh, Pa., 15209
Durabond, Inc., 1010 North Main St., Elkhart, Ind., 46514
Durex Products, Inc., Natl. Wire Cloth Div., Luck, Wisc., 54853
Duriron Co., Inc., The, 450 N. Findlay St., Dayton, Ohio, 45404
Dynex Div., Applied Power Inc., 770 Capitol Dr., Pewaukee, Wis., 53072
Dyson, Jos., & Sons Inc., 53 Freedom Rd., Painesville, Ohio, 44077

E

Eagle Crusher Co., Inc., Rt. 2, Box 72, Galion, Ohio, 44833
● Eagle Iron Works, 129 Holcomb Ave., Des Moines, IA, 50313
East Penn Mfg. Co., Lyon Station, Pa., 19536
Easton Car & Construction Co., Holly & Liberty Sts., Easton, Pa., 18042
Eaton Corp., World Headquarters, 100 Erieview Plaza, Cleveland, Ohio, 44114
Eaton Corp., Axle Div., 739 E. 140 St., Cleveland, Ohio, 44110
Eaton Corp., Forestry & Construction Equipment Div., Trojan Circle, Batavia, N.Y., 14020
Eaton Corp., Hoisting Equipment Div., Hwy. 1, North, Forrest City, Ark., 72335
Eaton Corp., Industrial Drives Div., 9919 Clinton Rd., Cleveland, Ohio, 44111
Eaton Corp., Transmission Div., 222 Mosel Ave., Kalamazoo, Mich., 49007
Economy Fuse Div., Federal Pacific Elec. Co., 2070 Maple St., Des Plaines, Ill., 60016
Edmont-Wilson, Div. of Becton, Dickinson & Co., 3172 Walnut St., Coshocton, Ohio, 43812
Eickhoff America Corp., Manor Oak Bldg. #1, 1910 Cochran Rd., Pittsburgh, Pa., 15220
● Eimco Mining Machinery, Envirotech Corp., P.O. Box 1211, Salt Lake City, UT, 84110
Electric Machinery Mfg. Co., 800 Central Ave., Minneapolis, Minn., 55413
Electric Products Div., Portec Inc., 1725 Clarkstone Rd., Cleveland, Ohio, 44112
Electro, 15146 Downey Ave., Paramount, CA, 90723
Electrolect, 3407 Rose Ave., Ocean, N.J., 07712
Electro Lite Battery Co., 1225 East 40th St., Chattanooga, Tenn., 37407
● Electro Switch Corp., King Ave., Weymouth, Mass., 02188
● El-Jay, Inc., P.O. Box 607, Eugene, Ore., 97401
Electronized Chemicals Corp., S. Bedford St., Burlington, Mass., 01803
Elkhorn Industrial Products Corp., P.O. Box 652, Martin, Ky., 41649
● ELMAC Corp., P.O. Box 1692, Huntington, W. Va., 25717
Emeco Inc., 111 Van Riper Ave., Elmwood Park, N.J., 07407
Energy Packaging, Inc., P.O. Box 22, Virginia, MN, 55792
ENERPAC, Div. of Applied Power Inc., Butler, Wis., 53007
English Drilling Equipment Co. Ltd., Lindley Moor Rd., Huddersfield HD3 3RW, Yorkshire, England
Ensign Bickford Co., The, P.O. Box 7, Simsbury, Conn., 06070
Ensign Electric Div., Harvey Hubbell Inc., 914 Adams Ave., P.O. Box 820, Huntington, W. Va., 25712
Enterprise Fabricators, Inc., Box 151, Bristol, Va., 24201
Entoleter Inc., P.O. Box 1919, New Haven, Conn., 06509
Environeering, Inc., 7401 N. Hamlin, Skokie, Ill., 60076
Envirex, Inc., 1901 S. Prairie, Waukesha, WI, 53186
Enviro-Clear, a Div. of Amstar Corp., Readington Rd. & Industrial Pkwy., Somerville, N.J., 08876
Environmental Control Systems, Inc., P.O. Box 167, Gallaway, Tenn., 38036
Environmental Equip. Div., FMC Corp., 1800 FMC Dr. West, Itasca, IL, 60143
Envirosphere Co., 21 West St., New York, N.Y., 10006
Envirotech Corp., Eimco BSP Div., 669 W. 2nd South, Salt Lake City, Utah, 84110
Epling Mfg. Co., Inc., P.O. Box 756, Grundy, Va., 24614
E-Power Industries Corp., 211 Mississippi, Box 2040, Wichita Falls, Tex., 76307
● Equipment Corp. of America, Box 306, Coraopolis, PA, 15108
Equipment Mfg. Services, Inc., RD 2, Box 70, Harmony, Pa., 16037
Erico Products, Inc., 34600 Solon Rd., Solon, Ohio, 44139
● Eriez Magnetics, 381 Magnet Dr., Erie, Pa., 16512
● ESCO Corp., 2141 N.W. 25th St., Portland, Ore., 97210
● Euclid, Inc., Sub. of White Motor Corp., 22221 St. Clair Ave., Cleveland, Ohio, 44117
Eutectic Corp., 40-40 172nd St., Flushing, NY, 11358
Everson Electric Co., P.O. Box 2688, Lehigh Valley, PA, 18001
Excoa, Inc., 11441 Willows Rd., Redmond, Wash., 98052
Exide Power Systems Div., ESB Inc., Rising Sun and Adams Ave., Philadelphia, Pa., 19120
Exxon Co., U.S.A., P.O. Box 2180, Houston, Tex., 77001

F

FAG Bearings Corp., Hamilton Ave., Stamford, Conn., 06904
FMC Corp., Agricultural Machinery Div., 5601 E. Highland Ave., Jonesboro, Ark., 72401
FMC Corp., Bearing Div., 7601 Rockville Rd., Box 85, Indianapolis, Ind., 46206
FMC Corp., Chain Div., 220 S. Belmont, Box 346B, Indianapolis, Ind., 46206
FMC Corp., Crane & Excavator Div., 1201 Sixth St., S.W., Cedar Rapids, Iowa, 52406
FMC Corp., Drive Div., 2045 W. Hunting Park Ave., Philadelphia, Pa., 19140
FMC Corp., Link-Belt Material Handling Systems Div., 3400 Walnut St., Colmar, Pa., 18915
FMC Corp., Material Handling Equipment Div., 708 Lexington Ave., Homer City, Pa., 15748
● FMC Corp., Mining Equipment Div., Drawer 992, Fairmont, W. Va., 26554
FMC Corp., Pump Div., 2005 Northwestern Ave., Indianapolis, Ind., 46208
FMC Corp., Steel Products Div., Box 1030, Anniston, Ala., 36201
Fabreeka Products Co., P.O. Box F/1190 Adams St., Boston, MA, 02124
● Fabricated Metals Industries, Inc., P.O. Box 8336, Roanoke, Va., 24014
Fabri-Valve, P.O. Box 4367, Portland, OR, 97208
Fafnir Bearing Div. of Textron Inc., 37 Booth St., New Britain, Conn., 06050
● Fagersta, Inc., #2 Henderson Dr., W. Caldwell, N.J., 07006
Failing, George E., Co., A Div. of Azcon Corp., 2215 S. Van Buren, P.O. Box 872, Enid, Okla., 73701
Fairbanks Co., The, 2 Glenwood Ave., Binghamton, N.Y., 13902
Fairbanks Morse Engine Div., Colt Industries, 701 Lawton Ave., Beloit, Wis., 53511
Fairbanks Weighing Div., Colt Industries, 711 E. St. Johnsbury Rd., St. Johnsbury, Vt., 05819
● Fairchild, Inc., P.O. Box 890, Beckley, W. Va., 25801
Fairfield Engineering Co., 324 Barnhart St., Marion, Ohio, 43302
Fairmont Supply Co., Box 501, Washington, Pa., 15301
● Falk Corp., The, Box 492, Milwaukee, Wis., 53201
Farrell-Cheek Steel Co., 706 Lane St., Sandusky, Ohio, 44870
Fastener House, Inc., 2231 Saw Mill Run Blvd., Pittsburgh, Pa., 15210
Fate-International Ceramic & Processing Equipment, Div. of the Fate-Root-Heath Co., a Banner Co., Bell & High Sts., Plymouth, Ohio, 44865
● Fate-Root-Heath Co., Plymouth Locomotives Div., Autolift Ind. Trucks Div., Bell & High Sts., Plymouth, Ohio, 44865
Federal Metal Hose Corp., P.O. Box 548, Painesville, Ohio, 44077
Federal-Mogul Corp., P.O. Box 1966, Detroit, Mich., 48235
Federal Supply & Equipment Co., Inc., Box 127, 4000 Parkway Lane, Hilliard, Ohio, 43026
Feeco International, Inc., 3913 Algoma Rd., Green Bay, WI, 54301
Femco Div., Gulton Industries, Inc., P.O. Box 33, 2000 Bethel Dr., High Point, N.C., 27261
● Fenner America Ltd., 400 East Main St., Middletown, Conn., 06457
Fenner, J. H. & Co., Ltd., Marfleet Hull, Yorkshire, England, HU9 5RA
Ferguson, H.K., Co., One Erieview Plaza, Cleveland, Ohio, 44114
Fermont Div., Dynamics Corp. of America, 141 North Ave., Bridgeport, Conn., 06606
Ferro-Tech, Inc., 1231 Banksville Rd., Pittsburgh, Pa., 15216
● Fiat-Allis Construction Machinery, Inc., P.O. Box 1213, Milwaukee, WI, 53051
Fiberglass Resources Corp., Motor Ave., Farmingdale, N.Y., 11735
Fibre-Metal Products Co., Box 248, Concordville, Pa., 19331
Fidelity Electric Co. Inc., 332 North Arch St., Lancaster, Pa., 17604
Fil-T-Vac Corp., P.O. Box 27451, Tempe, Ariz., 85282
Finn Equipment Co., 2525 Duck Creek Rd., Cincinnati, Ohio, 45208
Fire Protection Supplies Inc., 501 Mercer St., Princeton, W. Va., 24740
● Firestone Tire & Rubber Co., 1200 Firestone Pkwy., Akron, Ohio, 44317
● First Colony Corp., P.O. Box 296, Greene & Acme Sts., Marietta, Ohio, 45750
Firstmark Morrison Inc., 107 Delaware Ave., Buffalo, N.Y., 14202
● First National Bank of Maryland, Energy Resources Div., 25 S. Charles St., Baltimore, Md., 21202
Fisher Controls Co., P.O. Box 190, Marshalltown, IA, 50158
Fisher Scientific Co., 711 Forbes Ave., Pittsburgh, Pa., 15219
Flat Top Insurance Co., P.O. Box 439, Bluefield, W. Va., 24701
● Fleetguard, 8204 Elmbrook, Suite 250, Dallas, Tex., 75247
Fletcher, J. H., & Co., P.O. Box 2143, Huntington, W. Va., 25722
Fletcher Sutcliffe Wild, Ltd., Horbury, Wakefield, Yorkshire, England
Flexaust Co., Div. of Callahan Mining, 11 Chestnut St., Amesbury, MA, 01913
● Flexible Steel Lacing Co., 2525 Wisconsin Ave., Downers Grove, Ill., 60515
Flexible Valve Corp., 9 Empire Blvd., South Hackensack, N.J., 07606
Flexo Products, Inc., 24864 Detroit Rd., Westlake, Ohio, 44145
Flexowall Corp., Box 158, Kew Gardens, N.Y., 11415
Flood City Brass & Electric Co., Messenger & Elder Sts., Johnstown, Pa., 15907
● Flowers Transportation, Inc., P.O. Box 1588, Greenville, Miss., 38701
Fluid Controls Inc., 8341 Tyler Blvd., Mentor, Ohio, 44060
Fluidrive Engineering Co. Ltd., Fluidrive Works, Worton Rd., Isleworth, Middlesex, England, TW7 6EH
Flygt Corp., 129 Glover Ave., Norwalk, Conn., 06856
Foote Mineral Co., Route 100, Exton, Pa., 19341
Ford Div. of Ford Motor Co., Rotunda Dr. at Southfield, Dearborn, Mich., 48121
Ford Steel Co., 2475 Rock Island Blvd., St. Louis, Mo., 63043
● Ford Tractor & Implement, 2500 E. Maple Rd., Troy, Mich., 48084
Formsprag Co., 23601 Hoover Rd., P.O. Box 778, Warren, Mich., 48090
● Fort Pitt Steel Casting, 200 25th St., McKeesport, Pa., 15134
Foster, L. B., Co., 415 Holiday Dr., Pittsburgh, Pa., 15220
Foxboro Co., The, 38 Neponset Ave., Foxboro, Mass., 02035
Frazer & Jones, Box 1155, Syracuse, N.Y., 13201
Fredrik Mogensen AB, Box 78, S-544 00 HJO, Sweden
Frick-Gallagher Mfg. Co., The, 201 S. Michigan Ave., Wellston, Ohio, 45692
Frog Switch Mfg. Co., East Louther St., Carlisle, Pa., 17013
Fruehauf Div., Fruehauf Corp., 10900 Harper, Detroit, Mich., 48232
Fuller Co., A Gatx Co., P.O. Box 29, Catasauqua, Pa., 18032
Fullerton, Hodgart & Barclay Ltd., Vulcan Works, Renfrew Rd., Paisley PA3 4BE, Scotland

G

GAF Corp., 140 W. 51st St., New York, N.Y., 10020
GCA Technology Div., Burlington Rd., Bedford, Mass., 01730
GEC Mechanical Handling Ltd., Birch Walk, Erith, Kent DA8 1QH, England
GMC Truck & Coach Div., 660 So. Boulevard E., Pontiac, Mich., 48053
GTE Sylvania Inc., 100 First Ave., Waltham, Mass., 02154
G & W Electric Specialty Co., 3500 W. 127th St., Blue Island, Ill., 60406
Ga-Tronics Corp., 400 E. Wyomissing Ave., Mohnton, Pa., 19540
Galigher Co., The, 440 W. 8th S., P.O. Box 209, Salt Lake City, Utah, 84110
Galion Manufacturing Div., Dresser Industries, Inc., P.O. Box 647, Galion, Ohio, 44833
Gammeter, W. F., Co., P.O. Box 307, Cadiz, Ohio, 43907
Gardner-Denver Co., P.O. Box 1020, Denver, Colo., 80201
Garland Mfg. Co., Ironton, Minn., 56455
Gates Engr. Co., 201 N. Kanawha St., Beckley, W. Va., 25801
● Gates Rubber Co., The, 999 South Broadway, Denver, Colo., 80217
Gauley Sales, Inc., P.O. Box 308, Gauley Bridge, W. Va., 25085
General Aluminum Smelting Co., P.O. Box 11430, Kansas City, Mo., 64112
General Aviation Div., Rockwell International, 5001 N. Rockwell Ave., Bethany, Okla., 73008
● General Battery Corp., Box 1262, Reading, Pa., 19603
General Cable Corp., 500 W. Putnam Ave., Greenwich, Conn., 06830
General Electric Co., Carboloy Systems Dept., Box 237, General Post Office, Detroit, Mich., 48232
General Electric Co., DC Motor & Generator Dept., 3001 E. Lake Rd., Erie, Pa., 16531
General Electric Co., Industrial Sales Div., 1 River Rd., Schenectady, N.Y., 12345
General Electric Co., Instrument Products Operation, 40 Federal St., Lynn, Mass., 01910
General Electric Co., Insul. Mtls., 1 Campbell Road, Schenectady, N.Y., 12306
General Electric Co., Lamp Marketing Dept., Nela Park, Cleveland, Ohio, 44112
General Electric Co., Locomotive Products Dept., 2901 E. Lake Rd., Erie, Pa., 16501
General Electric Co., Mobile Radio Dept., P.O. Box 4197, Lynchburg, Va., 24502
General Electric Co., Power Circuit Breaker Dept., Section 1, 6901 Elmwood Ave., Philadelphia, Pa., 19142
General Electric Co., Transportation Systems Business Div., 2901 E. Lake Rd., Erie, Pa., 16501
General Electric Co., Wire and Cable Dept., 1285 Boston Ave., Bridgeport, Conn., 06602
General Electric Co., Wiring Device Product Dept., 95 Hathaway St., Providence, R.I., 02904
General Electric Credit Corp., Pittsburgh, Pa., 15205
General Equipment & Mfg. Co., Inc., 3300 Fern Valley Rd., Louisville, Ky., 40213
General Kinematics Corp., 777 Lake Zurich Rd., Barrington, Ill., 60010
General Refractories Co., U.S. Refractories Div., 600 Grant St., Pittsburgh, Pa., 15219
General Resource Corp., 201 S. 3rd St., Hopkins, Minn., 55343
General Scientific Equipment Co., Limekiln Pike & Williams Ave., Philadelphia, Pa., 19150
General Splice Corp., Box 392, Croton Dam Rd., Croton Hudson, N.Y., 10520
General Supply & Leasing Co., 64 Kansas Ave., Kansas City, Kan., 66105
General Tire & Rubber Co., The, One General St., Akron, Ohio, 44309
GenRad, 300 Baker Ave., Concord, Mass., 01742

● Geometrics, 395 Java Dr., Sunnyvale, Cal., 94086
GEOMIN, Calea Victoriei 109, Bucharest, Romania
George Evans Corp., The, 121 37th St., Moline, Ill., 61265
Gilson Screen Co., P. O. Box 99, Malinta, Ohio, 43535
Globe Battery Div., Globe Union Inc., 5757 N. Greenbay Ave., Milwaukee, Wis., 53201
Globe Safety Products, Inc., 125 Sunrise Pl., Dayton, Ohio, 45407
Glosser, M., and Sons, Inc., 72 Messenger St., Johnstown, Pa., 15902
Golder Associates, Inc., 10628 N.E. 38th Pl., Kirkland, Wash., 98033
Goodall Rubber Co., Whitehead Rd., Trenton, N. J., 08604
Goodbary Engineering Co., 1518-R So. Norfolk, Tulsa, Okla., 74120
Goodman Equipment Corp., 4834 South Halsted St., Chicago, Ill., 60609
Goodrich, B. F., Chemical Co., 6100 Oak Tree Boulevard, Cleveland, Ohio, 44131
● Goodrich, B. F.-Engineered Systems Co., 500 S. Main St., Akron, Ohio, 44318
Goodyear Tire & Rubber Co., 1144 E. Market St., Akron, Ohio 44316
● Gorman-Rupp Co., The, P. O. Box 1217, Mansfield, Ohio, 44902
Gould Inc., Century Electric Div., 1831 Chestnut St., St. Louis, Mo., 63166
Gould Inc., Industrial Battery Div., 2050 Cabot Blvd. W., Langhorne, Pa., 19047
Goulds Pumps, Inc., 240 Fall St., Seneca Falls, N. Y., 13148
Goyne Pump Co., East Centre St., Ashland, Pa., 17921
Grace, W.R. & Co., Construction Products Div., 62 Whittemore Ave., Cambridge, Mass., 02140
Great Lakes Instruments, Inc., 7552 N. Teutonia Ave., Milwaukee, Wisc., 53209
Green International, Inc., 2015 Grand Ave., Des Moines, Iowa, 50312
● Greenbank Cast Basalt Eng. Co. Ltd., Gate St., Blackburn, Lancs., England
Greengate Industrial Polymers Ltd., Irwell Works, Ordsall Lane, Salford M5 4TD, England
Greening Donald Co. Ltd., P.O. Box 430, Hamilton, Ont., Canada
Greenville Steel Car Co., Greenville, Pa., 16125
Griffolyn Co., Inc., P. O. Box 33248, Houston, Tex., 77033
Grimes-CWI Distributing Co., 655 Brea Canyon Rd., Walnut, Cal., 91789
Gruendler Crusher & Pulverizer Co., 2917 N. Market St., St. Louis, Mo., 63106
Gruner, Div. of Smith International, Inc., Drawer 911, Ponca City, Okla., 74601
Gulf Oil Chemicals Co., P.O. Box 2100, Houston, Tex., 77001
● Gulf Oil Corp., Dept. DM, P.O. Box 1563, Houston, Texas, 77001
● Gulf States Paper Corp., P.O. Box 3199, Tuscaloosa, Ala., 35401
● Gullick Dobson Intl. Ltd., P.O. Box 12, Wigan, Lancashire, England, WN1 3DD
Gundlach, T. J., Machine Co., Div. J. M. J. Industries, Inc., P. O. Box 385, Belleville, Ill., 62222
Gunson's Sortex (Mineral & Automation) Ltd., Hyde Industrial Estate, The Hyde, London NW9 6PX, England
Gustin-Bacon Div., Aero[illegible] Corp., P.O. Box 366, Lawrence, Kan., 66044
Guyan Machinery Co., P. O. Box 150, Logan, W. Va., 25601

H

Hacker Instruments Inc., P. O. Box 657, Fairfield, N. J., 07006
Hägglund & Söner, AB, Fack, 891 01 Örnsköldsvik 1., Sweden
Hahn Industries, Mine & Mill Specialties, 50 Broadway, New York, N. Y., 10004
Halecrest Co., Mt. Hope Mine Div., Mt. Hope Rd., Mt. Hope, N. J., 07885
Halliburton Services-Research Center, P.O. Box 1431, Duncan, Okla., 73533
● Haltec Seals Inc., 1929 Lakeview Dr., Fort Wayne, Ind., 46808
Hammermills, Inc., Sub. of Pettibone Corp., 625 C Ave., N. W., Cedar Rapids, Iowa, 52405
Hammond, J. V. Co., N. 1st St., Spangler, Pa., 15775
Hanco International Div. of Hannon Electric Co., 1605 Waynesburg Rd., Canton, Ohio, 44707
Hanson, R.A., Disc., Ltd., P. O. Box 7400, Spokane, Wash., 99207
Hardman Inc., Belleville, N.J., 07109
Hardy Plants, 587 Harmony Rd., New Brighton, Pa., 15066
Hardy Salt Co., P. O. Drawer 449, St. Louis, Mo., 63166
Harnischfeger Corp., P.O. Box 554, Milwaukee, Wis., 53201
Harrington & King Perforating, 5655 Fillmore St., Chicago, Ill., 60644
Hauck Mfg. Co., P.O. Box 90, Lebanon, Pa., 17042
● Haulmasters, Inc., 1212 So. Parker Rd., Olathe, Kan., 66061
Hawker Siddeley Dynamics Engineering Limited, Manor Road, Hatfield, Herts.
Hawker Siddeley Electric Export Ltd., P.O. Box 20, Loughborough, Leics. LE11 1HN, England
Hayden-Nilos Conflow Ltd., Triumph Rd., Lenton, Nottingham, England, NG7 2GF
Hazen Research, Inc., 4601 Indiana St., Golden, Colo., 80401
HB Electrical Mfg. Co., P.O. Box 1466, Mansfield, Ohio, 44901
Head Wrightson & Co. Ltd., The Friarage, Yarm-on-Tees, Stockton, Cleveland, England, TS17 6AZ
Heil Process Equipment Co., Div. of Dart Industries, Inc., 34250 Mills Rd., Avon, Ohio, 44011
Heintz Manufacturers, Inc., 6229 Grafton Rd., Valley City, Ohio, 44280
● Helwig Carbon Products, Inc., 2550 N. 30th St., Milwaukee, Wis., 53210
● Hemscheidt America, Ste. 660, Manor Oak No. 1, Pittsburgh, Pa., 15220
● Henderson Gear Corp., Venetia Rd., Venetia, Pa., 15367
Hendrick Mfg. Co., Lock Box 497, Carbondale, Pa., 18407
Hendrix Mfg. Co., Inc., P. O. Box 919, Mansfield, La., 71052
Hensley Industries Inc., 2108 Joe Field Rd., Dallas, Tex., 75229
Hercules Inc., Hercules Tower, 910 Market St., Wilmington, Del. 19899
Herold Mfg. Co., 215 Hickory St., Scranton, Pa.
Hewitt-Robins Conveyor Equipment Div., Litton Systems, Inc., 270 Passaic Ave., Passaic, N. J., 07055
Hewitt-Robins Div., Litton Systems, Inc., P.O. Box 1481, Columbia, S.C., 29202
Hewlett Packard, 815 14th St., S.W., P.O. Box 301, Loveland, Colo., 80537
● Heyl & Patterson, Inc., 7 Parkway Center, Pittsburgh, Pa., 15220
HITCO, Sub. of Armco Steel Corp., Box 1097, Alondra Station, Gardena, Cal., 90249
Hobart Bros. Co., 600 W. Main St., Troy, Ohio, 45373
Hoffman Diamond Products, Inc., Tiona & Cedar Sts., Punxsutawney, Pa., 15767
Holley, Kenney, Schott, Inc., 921 Penn Ave., Pittsburgh, Pa., 15222
Holmes Bros. Inc., 510 Junction Ave., Danville, Ill., 61832
Holz Rubber Co., A Randron Div., P.O. Box 109, 1129 Sacramento St., Lodi, Calif., 95240
Homelite Div., Textron Inc., P. O. Box 7047, Charlotte, N. C., 28217
Homestead Industries, Inc., P.O. Box 348, Coraopolis, Pa., 15108
Honeywell Inc., Process Control Div., 1100 Virginia Dr., Fort Washington, Pa., 19034
Hossfeld Mfg. Co., 440 W. Third St., Winona, Minn., 55987
Houdaille Hydraulics, 537 E. Delavan Ave., Buffalo, N.Y., 14211
Houghton & Co., E. F., 303 W. Lehigh Ave., Philadelphia, Pa., 19133
Howe Richardson Scale Co., 680 Van Houten Ave., Clifton, N. J., 07015
Hoyt Wire Cloth Co., 10 Abraso St., Box 1577, Lancaster, Pa., 17604
Huber Corp., Div. of A.T.O. Inc., 200 No. Greenwood St., Marion, OH, 43302
Hubinger Co., The, Keokuk, Iowa, 52632
Hughes, L. J., & Sons, Inc., 320 Turnpike Rd., Summersville, W. Va., 26651
Hughes Image Devices, 6855 El Camino Real, Carlsbad, Cal., 92008
Hughes Tool Co., P. O. Box 2539, Houston, Tex., 77001
● Hulburt Oil & Grease Co., 2200 East Castor Ave., Philadelphia, Pa., 19134
Hunslet Holdings Ltd., Hunslet Engine Works, Leeds LS10 1BT, England
Huntec (70) Ltd., 25 Howden Rd., Scarborough, Ont., Canada, M1 5A6
Huron Mfg. Corp., P.O. Box 1398, Huron, S.D., 57350
● Huwood Irwin Co., Box 409, Irwin, Pa., 15642
Huwood Limited, Gateshead, Tyne & Wear, NE11 0LP, England
HYCO, Inc., Sub. of The Weatherhead Co., 1401 Jacobson Ave., Ashland, Ohio, 44805
Hydraulic Products Inc., P.O. Box 458, Sturtevant, Wis., 53177
Hydreco, A Unit of General Signal, 9000 E. Michigan Ave., Kalamazoo, Mich., 49003
Hydr-O-Matic Pump Div., Weil McLain Co., Inc., Claremont & Baney, P.O. Box 327, Ashland, Ohio, 44805
Hy Test Safety Shoes Div. International Shoe Co., 1509 Washington Ave., St. Louis, Mo., 63166

I

I & M Equipment Sales, Inc., R # 1, Box 28M, Bourbon, Ind., 46504
I-T-E Imperial Corp., Norristown Rd., Spring House, Pa., 19477
ITT Grinnell Corp., 260 W. Exchange St., Providence, R.I., 02901
ITT Harper, 8200 Lehigh Ave., Morton Grove, Ill., 60053
ITT Holub Industries, 413 DeKalb Ave., Sycamore, Ill., 60178
ITT, Industrial & Automation Systems, 41225 Plymouth Rd., Plymouth, Mich., 48170
ITT Royal Electric, 95 Grand Ave., Pawtucket, R.I., 02862
ILG Industries, Div. of Carrier Corp., 2850 N. Pulaski Rd., Chicago, Ill., 60641
Illinois Gear/Wallace Murray Corp., 2108 N. Natchez Ave., Chicago, Ill., 60635
Impact Rotor Tool Inc., Route 30, E., Irwin, Pa., 15642
● Imperial-Eastman Corp., 6300 W. Howard St., Chicago, Ill., 60648
Imperial Oil & Grease Co., 10960 Wilshire Blvd., Los Angeles, Cal., 90024
Independent Explosives Co., 20950 Center Ridge Rd., Cleveland, Ohio, 44114
Indiana Steel & Fabricating Co., Rt. 286 So., Indiana, Pa., 15701
Industrial Contracting of Fairmont, Inc., P.O. Box 352, Fairmont, W. Va., 26554
Industrial Electric Reels Inc., 1125 Jackson St., Omaha, Neb., 68102
Industrial Pneumatic Systems, Sub. of Industrial Contracting of Fairmont, Inc., P.O. Box 352, Fairmont, W. Va., 26554
Industrial Rubber Products Co., P.O. Box 2348, 815 Court St., Charleston, W. Va., 25328
Industrial Steel Co., P. O. Box 504, Carnegie, Pa., 15106
Info Resometric Scale Inc., 2324 University Ave., St. Paul, Minn., 55114
● Ingersoll-Rand Co., Woodcliff Lake, N. J., 07675
Inland Steel Co., 30 W. Monroe St., Chicago, Ill., 60603
Insley Mfg., A Unit of AMCA Int'l. Corp., 801 N. Olney, P.O. Box 11308, Indianapolis, Ind., 46201
● International Alloy Steel Div., Curtis Noll Corp., 3917 St. Clair Ave., Cleveland, OH 44114
● International Harvester Co., 401 N. Michigan Ave., Chicago, Ill., 60611
International Salt Co., Clarks Summit, Pa., 18411
● Interstate Equipment Corp., 300 Mt. Lebanon Blvd., Pittsburgh, Pa., 15234
Iowa Industrial Hydraulics, Inc., Industrial Park Rd., Pocahontas, Iowa, 50574
Iowa Manufacturing Co., 916 16th St., N. E., Cedar Rapids, Iowa 52402
Iowa Mold Tooling Co., Inc., 500 Highway 18 West, Garner, Iowa, 50438
Irathane Systems, Inc., Industrial Park, Hibbing, Minn., 55746
Ireco Chemicals Co., Kennecott Bldg., Suite 726, Salt Lake City, Utah, 84111
Irwin-McKelvy Co., The, P. O. Box 767, Indiana, Pa., 15701
● ISCO Mfg. Co., P.O. Box 8620, Kansas City, Mo., 64114
Izumi Chain Co., 398 W. Wrightwood, Elmhurst, Ill., 60126

J

J-Tec Associates, Inc., 317 7th Ave., S.E., Cedar Rapids, Iowa, 52401
Jabco, Inc., 526 Ogle St., Ebensburg, Pa., 15931
Jaeger Machine Co., 550 W. Spring St., Columbus, Ohio, 43216
James, D. O. Gear Mfg. Co., Unit of Ex-Cell-O Corp., 1140 W. Monroe St., Chicago, Ill., 60607
● Janes Manufacturing Inc., 7625 S. Howell Ave., Oak Creek, Wis., 53154
Jarva, Inc., 29125 Hall St., Solon, Ohio, 44139
● Jeffrey Mfg. Div., Dresser Industries Inc., 912 No. Fourth St., Columbus, Ohio, 43216
● Jeffrey Mining Machinery Div., Dresser Industries Inc., 953 No. 4th St., Columbus, Ohio, 43216
Jenkins Bros., 100 Park Ave., New York, N. Y., 10017
Jenkins of Retford Ltd., Retford, Notts DN22 7AN, England
Jennmar Corp., P.O. Box 187, Cresson, Pa., 16630
● Jet Lube Inc., P.O. Box 21258, 4849 Homestead Rd., Houston, TX, 77026
Jim Bo's Food & Beverage Shoppes, P.O. Box 1535, Beckley, W. Va., 25801
Johnson Blocks Div., Don R. Henderiter, Inc., 1240 N. Harvard, P.O. Box 4699, Tulsa, Okla., 74104
Johnson Div., Universal Oil Products, P.O. Box 3118, St. Paul, Minn., 55165
Johnson March Corp., The, 3018 Market St., Philadelphia, Pa., 19104
Johnston Morehouse-Dickey Co., 5401 Progress Blvd., P.O. Box 173, Bethel Park, Pa., 15102
● Johnston Pump Co., 1775 E. Allen Ave., Glendora, Cal., 91740
Johnston Pump Co., Pittsburgh Branch, 1725 Washington Rd., Pittsburgh, Pa., 15241
Jold Mfg. Co., Inc., Box 341, Oakwood, Va., 24631
Jones & Laughlin Steel Corp., 3 Gateway Center, Pittsburgh, Pa., 15263
Jones & Laughlin Steel Corp., Conduit Products, McKees Lane, Niles, Ohio, 44446
● Joy Mfg. Co., Henry W. Oliver Bldg., Pittsburgh, Pa., 15222
Joy Mfg. Co., Denver Equipment Div., P. O. Box 22598, Denver, Colo., 80222
Joy Mfg. Co., Electrical Products Dept., 338 S. Broadway, New Philadelphia, Ohio, 44663
Joy Mfg. Co. (U.K.) Ltd., Burlington House, Chesterfield, Derbyshire S40 1SB, U.K.
Joy Service Center, Div. Joy Mfg. Co., P. O. Box 687, Bluefield, W. Va., 24701
Judson Rubber Works, Inc., 4107 W. Kinzie St., Chicago, Ill., 60624

K

K G Industries, Inc., 10225 Higgins Rd., Rosemont, Il., 60018
KHD Industrieanlagen AG, Humboldt Wedag, Wiersbergstrasse, D 5 Koeln 91, Fed. Rep. of Germany
K W Battery Co., a Div. of Westinghouse Electric Corp., 3555 Howard St., Skokie, Ill., 60076
Kaiser Aluminum & Chemical Corp., 942 Kaiser Bldg., 300 Lakeside Dr., Oakland, Calif., 94643
● Kaiser Engineers, Inc., 1818 Kaiser Center, 300 Lakeside Dr., Oakland, Cal., 94666
Kalenborn, Dr. Ing. Mauritz KG, D-5461 Kalenborn near Linz on Rhine, Germany
Kanawha Mfg. Co., P. O. Box 1786, Charleston, W. Va., 25326
Kay-Ray Inc., 516 W. Campus Dr., Arlington Heights, Il., 60004
Keenan Oil Co., 2350 Seymour Ave., Cincinnati, Ohio, 45212
● Kennametal Inc., Mining Tool Group, P.O. Box 346, Latrobe, Pa., 15650
Kennedy Metal Products & Buildings, Inc., Jack, Box 38, 200 S. Jayne St., Taylorville, Ill., 62568
Kennedy Van Saun Corp., Sub. of McNally Pittsburg, Danville, Pa., 17821
Kent Air Tool Co., 711 Lake St., Kent, Ohio, 44240
Kenworth Truck Co., P.O. Box 80222, Seattle, Wash., 98108
Kern Instruments Inc., 111 Bowman Ave., Port Chester, N.Y., 10573
Kersey Mfg. Co., P. O. Box 151, Bluefield, Va., 24605
Keystone Bolt Co., Sub. of Jennmar Corp., 600 Arch St., Cresson, PA, 16630
Keystone Div., Pennwalt Corp., 21 & Lippincott Sts., Philadelphia, Pa., 19132
Keystone Steel & Wire, Div. of Keystone Consolidated Industries, Inc., 7000 S.W. Adams, Peoria, Il., 61641
Kidde, Walter, & Co., Belleville Div., 675 Main St., Belleville, N.J. 07109
Kilborn-NUS, Inc., 600 S. Cherry St., Ste. 1235, Denver, Co., 80222
Kilo Wate Inc., Box 798, Georgetown, Tex., 78626
Kinetics, Inc., 1001 So. First St., Artesia, N. M., 88210
● Knaack Mfg. Co., 420 E. Terra Cotta Ave., Crystal Lake, Ill., 60014
Koch Engineering Co., Inc., 161 E. 42nd St., New York, N.Y., 10017
Kockums Industri AB, Fack, S-261 20 Landskrona, Sweden
● Koehring, Crane/Excavator Marketing Div., 780 N. Water St., Milwaukee, Wisc., 53201
Koehring Div. of Koehring Co., 3026 W. Concordia Ave., P.O. Box 422, Milwaukee, Wis., 53216
Kolberg Mfg. Corp., West 21 St., Yankton, SD 57078
Komatsu America Corp., 555 California St., Ste. 3050, San Francisco, Cal., 94104
Koppers Co., Inc., 1900 Koppers Bldg., Pittsburgh, Pa., 15219
● Koppers Co., Inc., Metal Products Div., Hardinge Operation, Box 312, York, Pa., 17405
Koppers Co. Inc., Metal Products Div., P.O. Box 298, Baltimore, Md., 21203
Krebs Engineers, 1205 Chrysler Dr., Menlo Park, Calif., 94025
● Kress Corp., 400 Illinois St., Brimfield, Ill., 61517
K-Tron Corp., P.O. Box 548, Glassboro, N. J., 08028

L

● L&M Radiator, Inc., 1414 E. 37th St., Hibbing, Minn., 55746
LaBour Pump Co., P.O. Box 1187, Elkhart, Ind., 46514
Ladish Co., 5401 S. Packard Ave., Box F, Cudahy, Wis., 53110
Lake Shore, Inc., P. O. Box 809, Iron Mountain, Mich., 49801
● LaMarche Manufacturing Co., 106 Bradrock Dr., Des Plaines, Ill., 60018
Laser Alignment, Inc., 6330 28th St., S.E., Grand Rapids, MI 49506

Laubenstein Mfg. Co., 418 S. Hoffman Blvd., Ashland, Pa., 17921
Laurel Corp., P.O. Box 206, Bluefield, W. Va., 24605
Lawrence Pumps, Inc., 371 Market St., Lawrence, Mass., 01843
Lebco, Inc., Illinois Div., Hiway 14E., P.O. Box 656, Benton, Ill., 62812
Lebus International Inc., Box 2352, Longview, Tex., 75601
Leco Corp., 3000 Lakeview Ave., St. Joseph, Mich., 49085
● Lee, A.L., & Co., Inc., 1186 Cleveland Ave. (P.O. Box 8085), Columbus, Ohio, 43201
Leeds & Northrup Co., Sumneytown Pike, North Wales, Pa., 19454
● Lee-Norse Co., Sub. of Ingersoll-Rand Co., 751 Lincoln Ave., Charleroi, Pa., 15022
Lee Supply Co., Inc., 130 Lincoln Ave., P.O. Box 35, Charleroi, Pa., 15022
Lehigh Safety Shoe Co., 1100 E. Main St., Endicott, NY, 13760
Le-Hi Valve & Coupling, Hose Products Div., Parker-Hannifin Corp., 30240 Lakeland Blvd., Wickliffe, Ohio, 44092
Le Roi Div., Dresser Industries, Inc., Main & Russell Rd., Sidney, Ohio, 45365
Lemon Machine Co., S. Railroad St., Portage, Pa., 15946
Leschen Wire Rope Co., Box 407, St. Joseph, Mo., 64502
● Liebherr America, Inc., 4100 Chestnut Ave., Drawer O, Newport News, Va., 23605
● Lightning Industries, Inc., 801 Westheather Rd., Kansas City., Mo., 64105
Lima Electric Co., Inc., 200 E. Chapman Rd., Lima, Ohio, 45802
Linatex Corp. of America, P.O. Box 65, Stafford Springs, Conn., 06076
Lincoln Electric Co., The, 22801 St. Clair Ave., Cleveland, Ohio, 44117
Lincoln St. Louis Div. of McNeil Corp., 4010 Goodfellow Blvd., St. Louis, Mo., 63120
Line Power Manufacturing Corp., 320 East Williams St., Bristol, Va., 24201
Lively Mfg. & Equipment Co., P. O. Box 338, Glen White, W. Va., 25849
Loftus, Peter F., Corp., Chamber of Commerce Bldg., Pittsburgh, Pa., 15219
Logan Corp., 555 7th Ave., P.O. Box 1895, Huntington, W. Va., 25719
● Long-Airdox Co. A Div. of the Marmon Group, Inc., P. O. Box 331, Oak Hill, W. Va., 25901
Longyear Co., 925 Delaware St. S.E., Minneapolis, Minn., 55414
Louis Allis Div., Litton Industrial Products, Inc., 427 E. Stewart St., Dept. CA, Milwaukee, Wis., 53201
Louisville & Nashville RR, 908 West Broadway, Louisville, KY, 40203
Lubrication Engineers, Inc., P.O. Box 7128, Ft. Worth, TX, 76111
Lubriplate Div., Fiske Brothers Refining Co., 129 Lockwood St., Newark, N.J., 07105
Lucas Industries, Fluid Power Div., P. O. Box 662, 30 Van Nostrand Ave., Englewood, N. J., 07631
Lucker Mfg. Co., 444 So. Henderson Rd., King of Prussia, Pa., 19406
Ludlow-Saylor Wire Cloth, Div. G.S.I., 8474 Delport Dr., St. Louis, Mo., 63114
Lukens Steel Co., W. Lincoln Highway, Coatesville, Pa., 19320
Lunkenheimer Co., Div. of Conval Corp., Sub. of Condec Corp., Beekman at Waverly Ave., Cincinnati, Ohio, 45214
Lyon Metal Prods. Inc., P.O. Box 671, Montgomery, IL, 60507

M

● 3 M Co., 3M Center, St. Paul, Minn., 55101
Mabscott Supply Co., Box 1560, Beckley, W. Va., 25801
Mac Products, Inc., 60 Pennsylvania Ave., Kearny, NJ, 07032
Macawber Engineering Ltd., Ogden Rd., Doncaster DN2 4SQ, England
MacDonald Engineering Co., 22 W. Madison St., Chicago, Ill., 60602
Machinery Center, Inc., 1201 S. 7th West P. O. Box 964, Salt Lake City, Utah, 84110
Machinoexport, 35 Mosfilmovskaya, Moscow M-330, USSR
● Mack Trucks, Inc., Box M, Allentown, Pa., 18105
Macwhyte Wire Rope Co., 2931 14th Ave., Kenosha, Wis., 53140
Majac Div., Donaldson Co., 5555 S. Garnett, Tulsa, Okla., 74145
Manganese Steel Forge, Taylor-Wharton Co., Div. of Harsco Corp., 2900 William Penn Highway, Easton, Pa., 18042
Manheim Mfg. & Belting, 311 W. Stiegel St., Manheim, Pa., 17545
Manitowoc Engineering Co., Div. Manitowoc Co., 500 S. 16th St., Manitowoc, Wis., 54220
Manson Services, Inc., R.D. #1, Box 307 A, Greensboro, Pa., 15338
Manufacturers Equipment Co., The, 35 Enterprise Dr., Middletown, Ohio, 45042
● Manufacturers Hanover Leasing Corp., 350 Park Ave., New York N.Y., 10022
Marathon Coal Bit Co., Inc., Box 391, Montgomery, W. Va., 25136
Marathon Letourneau Co., Longview Div., P. O. Box 2307, Longview, Texas, 75601
Marathon Mfg. Co., 600 Jefferson, 1900 Marathon Bldg., Houston, Tex., 77002
Marietta Concrete Co., P. O. Box 254, Marietta, Ohio, 45750
Marion Co., Div. of Sycon Corp., P.O. Box 491, Marion Ohio, 43302
● Marion Power Shovel Co. Inc., 617 W. Center St., Marion, Ohio, 43302
Mark Equipment Co., 6033 Manchester Ave., St. Louis, Mo., 63110
Marland One-Way Clutch Div., Zurn Industries, Inc., P. O. Box 308, La Grange, Ill., 60525
Marlin-Rockwell, Div. of TRW, Inc., 402 Chandler St., Jamestown, N. Y., 14701
Marmon Transmotive Div., Sanford Day Products, P. O. Box 1511, Knoxville, Tenn., 37901
Marquette Metal Prods. Co., 1145 Galewood Dr., Cleveland, Ohio, 44110
Marsh, E. F., Engineering Co., 1400 Hanley Industrial Dr., St. Louis, MO, 63144
Marlin Engrg. Co., U. S. Rte. 34, Neponset, Ill. 61345
Martindale Electric Co., 1307 Hird Ave., Cleveland, Ohio, 44107
● Massey-Ferguson Industrial & Construction Machinery, P. O. 1500, Akron, Ohio, 44309
Material Control, Inc., 719 Morton Ave., Aurora, Ill., 60506
● Mathews, Abe W., Engineering Co., 555 West 27th St., Hibbing, MN, 55746
● MATO, P. O. Box 70, D-6050 Offenbach (Main) 1, W. Germany
McBride Industries Inc., P.O. Box 94, St. Albans, W. Va., 25177
McDowell-Wellman Engrg. Co., 113 St. Clair Ave. N.E., Cleveland, Ohio, 44114
McGraw-Edison Co., Power Systems Div., P. O. Box 440, Canonsburg, Pa., 15317
McJunkin Corp., Charleston, W. Va.
McKee, Arthur G. & Co., Western Knapp Eng. Div., 2855 Campus Dr., San Mateo, Cal., 94403
McKey Perforating Co., Inc., 3033 So. 166th St., New Berlin, Wis., 53151
● McLanahan Corp., 200 Wall St., Hollidaysburg, Pa., 16648
● McLaughlin Mfg. Co., P.O. Box 303, Plainfield, IL 60544
McNally Pittsburg Mfg. Corp., 307 W. Third St., Pittsburg, Kan., 66762
Measurement & Control Systems Div., Gulton Industries Inc., Gulton Industrial Park, East Greenwich, R.I. 02818
Megator Corp., 136 Gamma Dr., Pittsburgh, Pa., 15238
Merkel Forsheda Corp., 5375 Naiman Parkway, Cleveland, Ohio, 44139
Mescher Mfg. Co. Inc., P. O. Box 789, Grundy, Va., 24614
Metal Carbides Corp., 6001 Southern Blvd., Youngstown, Ohio, 44512
Metex Corp., P.O. Box 10156, Helsinki 10, Finland
Metritape Inc., 33 Bradford St., West Concord, Mass., 01742
M/G Transport Services, Inc., 111 E. 4th St., Cincinnati, Ohio, 45202
● Michael Walters Ind., 6th & Pine St., Kenova, W. Va., 25530
● Michelin Tire Corp., Earthmover Tire Dept., 2500 Marcus Ave., Lake Success, N. Y., 11040
● Micro-Grade Laser Systems, Inc., 2352 Charleston Rd., Mountain View, Cal., 94043
Micro Switch, A Div. of Honeywell, 11 W. Spring St., Freeport, Ill., 61032
Midland Enterprises Inc., 580 Walnut St., Cincinnati, Ohio, 45402
Midland Pipe & Supply Co., 6111 W. 28 St., Cicero, Ill., 60650
Midland Pump, LFE Fluids Control Div., 100 Skiff St., Hamden, Conn., 06514
Midwestern Industries, Inc., Screen Heating Transformers Div., 915 Oberlin Rd., SW, Massillon, Ohio, 44646
Mid-Western Machinery Co., Inc., P. O. Box 458, Joplin, Mo., 64801
Midwest Steel Div., Midwest Corp., P. O. Box 271, Charleston, W. Va., 25321
Midwest Telecommunications Div., Midwest Corp., 300 First Ave., Nitro, W. Va., 25143
MikroPul Corp., 102 Chatham Rd., Summit, N. J., 07901
Mine Engineering & Development Co. (MEDCO), 2015 Grand Ave., Des Moines, Iowa, 50312
Mine Gas Monitors, Inc., P.O. Box 1361, Princeton, W. Va., 24740
Mine Management Systems, 306 Board of Trade Bldg., 12th & Chapline Sts., Wheeling, W. Va., 26003
● Mine Safety Appliances Co., 400 Penn Center Blvd., Pittsburgh, Pa., 15235
Mine & Smelter Industries, 3800 Race St., Denver, Colo., 80205
Mine Ventilation Systems, Inc., Box 985, Madison, W. Va., 25130
Mineral Services Inc., 1276 West Third St., Cleveland, Ohio, 44113
Minerals Processing Co., Div. of Trojan Steel Co., 315 "C" St., St. Albans, W. Va., 25177
Mining Developments Ltd., Crown Lane, Horwich, Bolton, BL6 5HH, England
Mining Equipment Mfg. Corp., 3319 Four Mile Rd., Racine, Wis., 53404
Mining Machine Parts, Inc., 6345 Norwalk Rd., Medina, Ohio, 44256
● Mining Progress, Inc., 605 Nelson Bldg., Charleston, W. Va., 25301
Mining Supplies, Ltd., Hillcrest Works, Carr Hill, Balby, Doncaster, S. Yorks, U.K.
● Mining Tools, Inc., 7700 St. Clair St., Mentor, Ohio, 44060
Minnesota Automotive Inc., Box 2074, North Mankato, Minn., 56001
Mintec/International, Div. of Barber-Greene, 400 N. Highland Ave., Aurora, Ill., 60507
Mixing Equipment Co., A Unit of General Signal, 135 Mt. Read Blvd., Rochester, N. Y., 14603
● Mobile Drilling Co., Inc., 3807 Madison Ave., Indianapolis, Ind., 46227
● Mobil Oil Corp., 150 E. 42nd St., New York, N. Y., 10017
Modern Engineering Co., P.O. Box 14858, St. Louis, Mo., 63178
Molded Dimensions Inc., 701 Sunset Rd., Pt. Washington, Wisc., 53074
Monitor Mfg. Co., 200 N. Island Ave., Batavia, Ill., 60510
Monitrol Mfg. Co., P.O. Box 3296, Tyler, Texas, 75701
Monogram Industries, Inc., 4030 Freeman Blvd., Redondo Beach, Cal., 90278
Monsanto Co., 800 N. Lindbergh Blvd., St. Louis, Mo., 63166
Montreal Engineering Co. Ltd., P.O. Box 777, Place Bonaventure, Montreal, Canada
Moore Co., The, P. O. Box 753, Charleston, W. Va., 25323
Moore Industrial Battery Co., 4312-20 Spring Grove Ave., Cincinnati, Ohio, 45223
Moore, Samuel, & Co., Synflex Div., Mantua, Ohio, 44255
Morgantown Machine & Hydraulics, Inc., Div. Natl. Mine Service Co., P.O. Box 986, Morgantown, W. Va., 26505
Morris Pumps, Inc., 31 E. Genesee St., Baldwinsville, N. Y., 13027
Morse Bros. Machinery Co., 1290 Harlan St., Denver, Colo., 80214
Morse Chain, Div. of Borg Warner Corp., So. Aurora St., Ithaca, N. Y., 14850
Morse Controls Div., Rockwell Intl., 21 Clinton St., Hudson, Ohio, 44236
Morton Salt Co., 110 N. Wacker Dr., Chicago, Ill., 60606
Mosebach Manufacturing Co., 1115 Arlington Ave., Pittsburgh, Pa., 15203
Motorola Communications & Electronics, 1301 E. Algonquin Rd., Schaumburg, Ill., 60196
Mott, B. H., & Sons, Inc., 814-846 8th Ave., Huntington, W. Va., 25701
Multi-Amp Corp., 4271 Bronze Way, Dallas, Tex., 75237
Myers-Whaley Co., P. O. Box 4265, Knoxville, Tenn., 37921

N

N.L. Industries, Bearings Div., 5461 Southwyck Blvd., Toledo, Ohio, 43614
Nachod & U.S. Signal Co., 4777 Louisville Ave., Louisville, Ky., 40221
Nagle Pumps, Inc., 1249 Center Ave., Chicago Heights, Ill., 60411
● Nalco Chemical Co., 2901 Butterfield Rd., Oak Brook, Ill., 60521
● Nash Engineering Co., 310 Wilson Ave., Norwalk, Conn., 06856
National Air Vibrator Co., 6880 Wynnwood Lane, Houston, Texas, 77008
● National Car Rental Systems Inc., Medcat Div., P.O. Box 16247, St. Louis Park, Minn., 55416
● National Castings Div., Midland-Ross Corp., 2570 Woodhill Rd., Cleveland, Ohio, 44104
National Electric Cable, Div. National Electric Control Co., 2931 Higgins Rd., Elk Grove Village, Ill., 60007
National Electric Coil Div. of McGraw-Edison Co., 941 Chatham Lane, Suite 301, Columbus, Ohio, 43221
National Engineering Co., 20 North Wacker Dr., Suite 2060, Chicago, Ill., 60606
National Environmental Inst. Inc., P.O. Box 590, Pilgrim Station, Warwick, R.I., 02888
National Filter Media Corp., 1717 Dixwell Ave., Hamden, Conn., 06514
National Foam System Inc., 150 Gordon Dr., Lionville, Pa., 19353
● National Iron Co., 50 Ave. W. & Ramsey St., Duluth, Minn., 55807
● National Mine Service Co., 3000 Koppers Bldg., Pittsburgh, Pa., 15219
● National-Standard Co., Perf. Metals Div., 166 Dundaff St., Carbondale, Pa., 18407
National Supply Co., Div. of Armco Steel Corp., 1455 W. Loop South, Houston, Tex., 77027
Naylor Pipe Co., 1265 E. 92 St., Chicago, Ill., 60619
Neff & Fry, Inc., 150 S. Main St., Camden, Ohio, 45311
Nestle Co., Deer Park Spring Water, 100 Bloomingdale Rd., White Plains, N. Y., 10605
New York Blower Co., 3155 S. Shields Ave., Chicago, Ill., 60616
NFE International Ltd., 413 W. University Dr., Arlington Heights, Ill., 60004
Niles Expanded Metals, 403 No. Pleasant Ave., Niles, Ohio, 44446
● Nolan Co., The, Box 201, Bowerston, Ohio, 44695
Non-Fluid Oil Corp., 298 Delancy St., Newark, N. J., 07105
Norris Industries, Fire & Safety Equipment Div., P.O. Box 2750, U.S. Highway No. 1, Newark, N.J., 07114
North American Gase Co., Rte. 7 East, P.O. Box 3158, Morgantown, W. Va., 26505
North American Hydraulics, Inc., P.O. Box 15431, Baton Rouge, La., 70895
North American Mfg. Co., 4455 E. 71st St., Cleveland, Ohio, 44105
North American O&K, 222 S. Riverside Plaza, Chicago, Ill., 60606
North State Pyrophyllite Co., Inc., P. O. Box 7247, Greensboro, N. C., 27407
Northwest Engrg. Co., 201 West Walnut, Green Bay, Wi. 54305
Norton Co., 1 New Bond St., Worcester, Mass., 01606
Numonics Corp., 418 Pierce St., Ste. 3, Lansdale, Pa., 19446
NUS Corp., Robinson & Robinson Div., 1517 Charleston National Plaza, Charleston, W. Va., 25301

O

O & K Orenstein & Koppel AG, Karl-Funke-Str. 30, D-4600 Dortmund, Germany
Ocenco, Inc., Magna-Beam Div., P.O. Box 8, 101 Industrial Pk., Blairsville, Pa., 15717
● O'Donnell & Associates, Inc., 5100 Centre Ave., Pittsburgh, Pa., 15232
Ohio Brass Co., 380 N. Main St., Mansfield, Ohio, 44902
Ohio Carbon Co., 12508 Berea Rd., Cleveland, Ohio, 44111
Ohio River Co. The, P.O. Box 1460, Cincinnati, Ohio, 45201
Ohio Transformer Corp., P.O. Box 191, 1776 Constitution Ave., Louisville, Ohio, 44641
Ohmart Corp., 4241 Allendorf Dr. P. O. Box 9026, Cincinnati, Ohio, 45209
Oil Center Research, 320 Heymann Boulevard, Lafayette, La., 70501
Okonite Co., P. O. Box 340, Ramsey, N. J., 07446
Old Republic Insurance Co., 414 W. Pittsburgh St., Greensburg, Pa., 15601
Onox, Inc., 240 Hamilton Ave., Palo Alto, Ca., 94301
ORBA Corp., P.O. Box 571, Superior, Wisc. 54880
Ore Reclamation Co., 301 N. Connell Ave., Picher, Okla., 74360
Ortner Freight Car Co., 2652 Erie Ave., Cincinnati, Ohio, 45208
Oshkosh Truck Corp., P.O. Box 2566, Oshkosh, Wis., 54901
Osmose Wood Preserving Co. of America Inc., 980 Ellicott St., Buffalo, N. Y., 14209
Outokumpu Oy, Technical Export Div., P.O.B. 27, 02101 Espoo 10, Finland
● Over-Lowe Co., Inc., 2767 S. Tejon, Englewood, Colo., 80110
Owatonna Tool Co., 791 Eisenhower Drive, Owatonna, Minn., 55060
Owen Bucket Co., The, 6001 Breakwater Ave., Cleveland, Ohio, 44102
Owens-Corning Fiberglas Corp., Fiberglass Tower, Toledo, Ohio, 43659
● Owens Mfg., Inc., P. O. Box 1490, Bristol, Va., 24201

P

PLM Products, Div. Scott & Fetzer, 4799 W. 150 St., Cleveland, Ohio, 44135
PPG Industries, Inc., Chemical Div., One Gateway Center, Pittsburgh, Pa. 15222
Pace Transducer Co., Div. of C.J. Enterprises, P.O. Box 834, Tarzana, CA 91356
Paceco, A Div. of Fruehauf Corp., 2350 Blanding Ave., Alameda, Cal., 94501
● Padley & Venables Ltd., Callywhite Lane, Dronfield, Sheffield S18 6XT, England
Page Engrg. Co., Clearing Post Office, Chicago, Ill., 60638
● Pall Corp., 30 Sea Cliff Ave., Glen Cove, N. Y., 11542
● Palm Industries, Box 680, Litchfield, Minn., 55355
Parker-Hannifin Corp., Hose Products Div., 30240 Lakeland, Wickliffe, Ohio, 44092
Parker-Hannifin Corp., Power Units Div., 17325 Euclid Ave., Cleveland, Ohio, 44112
Parker-Hannifin Corp., Tube Fittings Div., 17325 Euclid Ave., Cleveland, Ohio, 44112

Parkson Corp., 5601 N.E. 14th Ave., Ft. Lauderdale, Fla. 33334
Patent Scaffolding Co., 2125 Center Ave., Fort Lee, N.J. 07024
Patterson-Kelley Co., Div. of Taylor Wharton Co. - Harsco Corp., 100 Burson St., East Stroudsburg, Pa. 18301
Pattin Manufacturing Co., Div. The Eastern Co., P.O. Box 659, Marietta, Ohio, 45750
Paulsen Wire Rope Corp., 2111 Tchoupitoulas St., New Orleans, La. 70130
Paurat GmbH, Nordstraße, 4223 Voerde 2, W. Germany
Peabody ABC, P.O. Box 187, Warsaw, Ind., 46580
Peabody Barnes, 615 N. Main St., Mansfield, Ohio, 44902
Peabody Galion Div. of Peabody Galion Corp., P.O. Box 607, Galion, Ohio, 44833
Peerless Conveyor & Mfg. Co., Inc., 3341 Harvester Rd., Kansas City, Kan. 66115
Peerless Hardware Mfg. Co., 210 Chestnut St., Columbia, Pa. 17512
● Pemco Corp., Box 1338, Bluefield, W. Va., 24701
● Penn Machine Co., 106 Station St., Johnstown, Pa. 15905
● Pennsylvania Crusher Corp., P. O. Box 100 CA, Broomall, Pa. 19008
Pennsylvania Electric Coil, Inc., 1301 Saw Mill Run Blvd., Pittsburgh, Pa. 15226
● Pennzoil Co., Drake Building, Oil City, Pa. 16301
Pennzoco, Div. Pennzoil Co., 106 S. Main St., Butler, Pa. 16001
Perard Engineering Ltd., Brittain Dr., Codnor Gate Ind. Estate, Ripley, Derbyshire DE5 3QB, England
Perkin-Elmer Corp., Main Ave., Norwalk, Conn. 06856
Persingers Inc., P.O. Box 1886, 520 Elizabeth St., Charleston, W. Va. 25327
Peterson Filters & Engineering Co., P.O. Box 606, Salt Lake City, Utah, 84110
Petrogen Inc., P.O. Box 1592, Richmond, Cal. 94802
Pettibone Corp., 4710 W. Div. St., Chicago, Ill. 60651
Pettibone Corp., Pettibone New York Div., 1212 E. Dominick St., Rome, N.Y. 13440
Phelps Dodge Industries, Inc., 300 Park Ave., New York, N.Y. 10022
● Philadelphia Gear Corp., 181 S. Gulph Rd., King of Prussia, Pa. 19406
Phillips-Hagenbuch Inc. Ltd., 1815 North Knoxville, Peoria, Ill. 61603
Phillips Mine & Mill, Inc., P. O. Box 70, Bridgeville, Pa. 15017
Phillips Products Co., Inc., Suite 120, Dallas, Tex. 75234
Phoenix Products Co., Inc., 4715 North 27th St., Milwaukee, Wis. 53209
Pioneer Mfg. Co., Div. A.B. Chance Co., P.O. Box 120, Grandview, Mo. 64030
Pittsburgh Corning Corp., 800 Presque Isle Dr., Pittsburgh, Pa. 15239
● Plastic Techniques, Inc., R.D. #3, Box 91, Clarks Summit, Pa. 18411
Plibrico Company, 1800 Kingsbury St., Chicago, Ill. 60614
● Plymouth Rubber Co., Inc., 51 Revere St., Canton, Mass. 02021
● Poly-Hi, Inc., 2710 American Way, Fort Wayne, Ind. 46809
● Portadrill, Div. of Smith International Inc., 2201 Blake St., Denver, Colo. 80205
Portec, Inc., Pioneer Div., 3200 Como Ave., S.E., Minneapolis, Minn. 55414
Porter, H.K. Co., Inc., Porter Bldg., Pittsburgh, Pa. 15219
Porter, H. K., Inc., 74 Foley St., Somerville, Mass. 02143
Porto Pump, Inc., 19735 Ralston, Detroit, Mich. 48203
Post-Glover Div., ESB Inc., Box 709, Covington, KY. 41012
Power Transmission Div., Dresser Industries, Inc., 400 W. Wilson Bridge Rd., Worthington, Ohio, 43085
Preiser/Mineco Div., Preiser Scientific Inc., Jones & Oliver St., St. Albans, W. Va. 25177
Prestolite Battery Div. of Eltra Corp., 511 Hamilton St., Toledo, Ohio, 43694
Prestolite Electrical Div. of Eltra Corp., P.O. Box 931, Toledo, Ohio, 43694
Prestolite Wire Div. of Eltra Corp., 3529 24th St., Port Huron, Mich. 48060
Princeton Aviation Corp., Teterboro Airport, Teterboro, N.J. 07608
Process Equipment, Stansteel Corp., 5001 S. Boyle Ave., Los Angeles, Cal. 90058
Process Metals Co., P. O. Box 905, Elkhart, Ind. 46514
Programmed & Remote Systems, 899 W. Highway 96, St. Paul, Minn. 55112
Prosser Industries, Div. of Purex Corp., P.O. Box 3818, Anaheim, Calif. 92803
Prox, Frank Co., Inc., P. O. Box 1484, 1201 S. 1st St., Terre Haute, Ind. 47808
Pullman Standard Div., Pullman Inc., 200 So. Michigan Ave., Chicago, Ill. 60604
Pullman Torkelson Co., 10 West Broadway, St. Lake City, Utah 84101
Pulmosan Safety Equip. Co., 30-48 Linden Pl., Flushing, N.Y. 11354
Pulverizing Machinery, Div. of MikroPul Corp., 10 Chatham Rd., Summit, N.J. 07901
Pure Carbon Co. Inc., 441 Hall Ave., St. Marys, Pa. 15857
Pure Way Corp., 301-42nd Ave. E. Moline, Ill. 61244
● Pyle National Co., 1334 North Kostner, Chicago, Ill. 60651
Pyott-Boone, Inc., P.O. Box 809, Tazewell, Va. 24651
● Pyott-Boone Machinery Corp., Saltville, Va. 24370

Q

Quest Electronics, 510 Worthington St., Oconomowoc, Wis. 53066
Quincy Compressor Div., Colt Industries, 217 Maine St., Quincy, Ill. 62301

R

RCA, Mobile Communications Systems, Meadow Land, Pa. 15347
RRL Controls, Hainesport Industrial Pk., Hainesport, N.J. 08036
RM Friction Materials Co., Div. Raybestos-Manhattan Inc., 100 Oakview Dr., Trumbull, Conn. 06611
RM Roll Products Co., Div. Raybestos-Manhattan, Inc., P.O. Box 157, Clark's Summit, Pa. 18411
Raco International, Inc., 3350 Industrial Blvd., Bethel Park, Pa. 15102
Raleweight, Inc., 1821 Willow Rd., Northfield, Ill. 60093
Ramsey Engineering Co., 1853 W. County Rd. C., St. Paul, Minn. 55113
Ransomes & Rapier Ltd., P.O. Box 1, Waterside Works, Ipswich IP2 8HL, England
Rapid Electric Co., Inc., Grays Bridge Rd., Brookfield, Conn. 06804
Raybestos-Manhattan Industrial Products Co., Garco St., No. Charleston, S.C. 29406
Raychem Corp., 300 Constitution Dr., Menlo Park, Calif. 94025
RayGo, Inc., 9401 - 85th Ave. No., Minneapolis, Minn. 55412
Red Comet, Inc., P. O. Box 272 Red Comet Bldg., Littleton, Colo. 80120
Red Valve Co., Inc., 500 Bell Ave., Carnegie, Pa. 15106
Red Wing Shoe Co., Inc., 419 Bush St., Red Wing, Minn. 55066
Redding Co., James A., 615 Washington Rd., Pittsburgh, Pa. 15228
Reed Manufacturing, P. O. Box 905, Walnut, Cal. 91789
Reed Tool Co., P.O. Box 2119, Houston, Tex. 77001
Reggie Industries, 15 Spinning Wheel Rd., Ste. 332, Hinsdale, Ill. 60521
Reinco Industries, P.O. Box 584, Plainfield, N.J. 07061
Reiss Viking Corp., Div. C. Reiss Coal Co., P. O. Box 3336, 1300 Georgia Ave., Bristol, Tenn. 37620
● Reliance Electric Co., 24701 Euclid Ave., Cleveland, Ohio, 44117
Rema-Tech, 200 Paris Ave., Northvale, N.J. 07647
Republic Steel Corp., P. O. Box 6778, 1441 Republic Bldg., Cleveland, Ohio, 44101
Research Cottrell, Inc., P.O. Box 750, Bound Brook, N.J. 08805
● Research Energy of Ohio, 237 Charleston St., Cadiz, Ohio, 43907
Results-Loy Co., 1251 Phillips Ave., S. W., Grand Rapids, Mich. 49507
Revere Corp. of America, Sub. of Neptune Intl. Corp., North Colony Rd., Wallingford, Conn. 06492
Rexarc, Inc., Rexarc Place, West Alexandria, Ohio, 45381
● Rexnord Inc., P.O. Box 2022, Milwaukee, Wis. 53201
● Rexnord Inc., Process Machinery Div., Box 383, Milwaukee, Wis. 53201
Reynolds Metals Co., P. O. Box 27003, Richmond, Va. 23261
Richmond Mfg. Co., P.O. Box 188, Ashland, Ohio, 44805
Ridge Tool Co., Sub. of Emerson Electric Co., 400 Clark St., Elyria, Ohio, 44035
Rigco, Inc., 251 S. 3rd St., Oxford, Pa. 19363
Rise Corp., 37 Midland Ave., Elmwood Park, N.J. 07407
Rish Equipment Co. Intl., P.O. Box 429, St. Albans, W. Va. 25177
Rish Equipment Co., Material Handling Systems Div., 2508 West Main St., Salem, Va. 24153
Riverside Polymer Corp., P.O. Box 313, Paterson, N.J. 07524
Robbins Co., 650 S. Orcas St., Seattle, Wash. 98108
Robbins Div., Joy Mfg. Co., 300 Fleming Rd. (P.O. Box 6505), Birmingham, Ala. 35217
Robbins & Myers, Inc., 1345 Lagonda Ave., Springfield, Ohio, 45501
Roberts & Schaefer Co., 120 S. Riverside Plaza, Chicago, Ill. 60606
Robicon Corp., 100 Sagamore Hill Rd., Plum Ind. Park, Pittsburgh, Pa. 15239
Robinson Industries, Inc., P.O. Box 100, Zelienople, Pa. 16063
Rochester Corp., P. O. Box 312, Culpeper, Va. 22701
Rock Industries Machinery Corp., 4603 W. Mitchell, Milwaukee, Wisc. 53214
Rock Tools, Inc., P.O. Box 17303, Salt Lake City, Utah, 84117
Rockwell International Flow Control Div., 400 N. Lexington Ave., Pittsburgh, Pa. 15208
Rockwell International Power Tool Div., 400 N. Lexington Ave., Pittsburgh, Pa. 15208
Rockwell-Standard Div., Rockwell International Corp., P. O. Box 641, Troy, Mich. 48084
Rohm and Haas Co., Independence Mall West, Philadelphia, Pa. 19105
Roller Corp., P.O. Box 12606, Pittsburgh, Pa. 15241
Rollway Bearing Co., P. O. Box 1397, Syracuse, N.Y. 13201
Rose Manufacturing Co., 2775 S. Vallejo, Englewood, Colo. 80110
Rost, H. & Co., Beleitroswerke, P.O. Box 1168, D-21 Hamburg 90, W. Germany
Round, David & Son, Inc., P. O. Box 39156, Cleveland, Ohio, 44139
Rubber Engineering & Mfg. Co., 3459 S. 700 West, Salt Lake City, Utah, 84107
Rust Engineering Co., A Sub. of Wheelabrator-Frye Inc., P.O. Box 101, 1130 South 22nd St., Birmingham, Ala. 35201
Rust-Oleum Corp., 2301 Oakton St., Evanston, Ill. 60204
Ruffmann Companies, 425 W. Walker St., P. O. Box 120, Upper Sandusky, Ohio, 43351
Ryerson, Joseph T. & Son, Inc., P. O. Box 8000A, Chicago, Ill. 60680

S

● S & S Machinery Sales, Inc., Route 1, Cedar Bluff, Va. 24609
St. Regis Paper Co., 150 E. 42nd St., New York, N.Y. 10017
SKF Industries, Inc., 1100 First Ave., King of Prussia, Pa. 19406
Sala International, S 733 00 Sala, Sweden
Sala Machine Works Ltd., 3136 Mavis St., Cooksville, Ont., Canada
● Salem Tool Co., The, 767 S. Ellsworth Ave., Salem, Ohio, 44460
Samson Supply & Mfg. Inc., P.O. Box 462, Waterloo, Iowa, 50704
Sanderson Cyclone Drill Co., 1250 E. Chestnut St., Orrville, Ohio, 44667
Sanford-Day/Marmon Transmotive, Div. of the Marmon Group, Inc., P.O. Box 1511, Gov. John Sevier Hwy., Knoxville, Tenn. 37901
Sangamo Electric Co., 1301 N. 11th St., Springfield, Ill. 62708
Sauerman Bros., Inc., 620 S. 28th Ave., Bellwood, Ill. 60104
Savage, W. J. Co., 912 Clinch Ave., S. W., Knoxville, Tenn. 37901
Scandura, Inc., P. O. Box 949, 1801 North Tryon St., Charlotte, N.C. 28201
● Schaefer Brush Mfg. Co., 117 W. Walker St., Milwaukee, Wis. 53204
Schaffer Poidometer & Machine Co., 2828 Smallman St., Pittsburgh, Pa. 15222
Schaumburg Flexaflux Corp., 12 A Buncher Ind. Dist., Leetsdale, Pittsburgh, Pa. 15056
● Schramm Inc., 901 E. Virginia Ave., West Chester, Pa. 19380
● Schroeder Bros. Corp., Nichol Ave., Box 72, McKees Rocks, Pa. 15136
Scott Aviation, A Div. of A.T.O. Inc., 225 Erie St., Lancaster, N.Y. 14086
Scott Midland Div., A.T.O. Inc., 11099 Broadway, Alden, N.Y. 14004
Screen Equipment Co., Div. Hobam Inc., 40 Anderson Rd., Buffalo, N.Y. 14225
Seiberling Tire & Rubber Co., 345 15th St., N.W., P.O. Box 189, Barberton, Ohio, 44203
Seminole Products Co., Inc., Box 123, Glendora, N.J. 08029
Seneca Helicopters Inc., P.O. Box 882, Oil City, Pa. 16301
Serpentix Conveyor Corp., 1550 S. Pearl St., Denver, Colo. 80210
Servus Rubber Co., 1136 Second St., Rock Island, Ill. 61201
Seton Name Plate Corp., 1654 Boulevard, New Haven, Conn. 06505
● Sevcon, Div. of Tech/Ops, 40-A South Ave., Burlington, Mass. 01803
Shannon Optical Co., Inc., 3825 Willow Ave., Pittsburgh, Pa. 15234
● Shaw-Almex Industries Ltd., P. O. Box 430, Parry Sound, Ont., Canada
Shell Chemical Co., Chemical Sales, P.O. Box 2463, Houston, Tex. 77001
Shell Oil Co., One Shell Plaza, Houston, Texas, 77002
Shingle, L.H. Co., 500 Gravers Rd., Plymouth Meeting, Pa. 19462
Shirley Machine Co., Div. Tasa Corp., Suite 2701, Gateway Towers, Pittsburgh, Pa. 15222
Shwayder Co., 2335 E. Lincoln, Birmingham, Mich. 48008
Siemens Corp., 186 Wood Ave., South, Iselin, N.J. 08830
Signaform Corp., 2401 Walsh Ave., Santa Clara, Cal. 95050
Si Drilco Industrial, Div. of Smith Intl. Inc., Drawer 3135, Midland, Tex. 79701
● Simplicity Engineering, 212 S. Oak St., Durand, Mich. 48429
Sioux Steam Cleaner Corp., Beresford, S.D. 57004
Sly, W. W. Mfg. Co., P.O. Box 5939, Cleveland, Ohio, 44101
Smico Corp., 500 N. Mac Arthur Blvd., Oklahoma City, Okla. 73127
Smit, J. K. & Sons, Inc., 571 Central Ave., Murray Hill, N.J. 07974
Smith, A. O. Inland Inc. Reinforced Plastics Div., 2700 West 65th St., Little Rock, Ark. 72209
Smith International Inc., 4667 Macarthur Blvd., Newport Beach, Calif. 92660
Smith Tool, 17871 Von Karman Ave., Irvine, Cal. 92714
Snap On Tools Corp., 8132 28th Ave., Kenosha, Wis. 53140
Soiltest, Inc., 2205 Lee St., Evanston, Ill. 60202
Solids Flow Control Corp., 37 Midland Ave., Elmwood Park, N.J. 07407
Somerset Welding & Steel Inc., 733 S. Center Ave., Somerset, Pa. 15501
Sonic Development Corp., 3 Industrial Ave., Upper Saddle River, N.J. 07458
Sortex Co. of North America, Inc., P.O. Box 160, Lowell, Mich. 49331
Southern Tire Co., 1414 Broadway, Sheffield, Ala.
Spang & Co., P. O. Box 751, Butler, Pa. 16001
Speakman Co., P. O. Box 191, Wilmington, Del. 19899
Specialty Surfaces, Inc., 6152 Steeplechase Dr., S.W., Salem, Va. 24153
Spectrum Infrared Inc., 246 E. 131st St., Cleveland, Ohio, 44108
Sperry Vickers Div., Sperry Rand Corp., P. O. Box 302, Troy, Mich. 48084
Sperry Vickers, Tulsa Div., P. O. Box G, Tulsa, Okla. 74115
Sprague & Henwood, Inc., 221 W. Olive St., Scranton, Pa. 18501
Spraying Systems Co., North Ave. at Schmale Rd., Wheaton, Ill. 60545
Sprengnether, W. F. Instrument Co. Inc., 4576 Swan Ave., St. Louis, Mo. 63110
Sprout Waldron, Koppers Co., Inc., Muncy, Pa. 17756
Square D Co., Executive Plaza, Park Ridge, Ill. 60068
Stamler, W. R. Corp., The, 600 Trigg St., Millersburg, Ky. 40348
Stanadyne/Hartford Div., Box 1440, Hartford, Conn. 06102
Stanco Mfg. & Sales Inc., 800 Spruce Lake Dr., Harbor City, Calif. 90710
Standard Metal Mfg. Co., P. O. Box 57, Malinta, Ohio, 43535
Stauffer Chemical Co., Specialty Chemical Div., Westport, Conn. 06880
Stearns Magnetics Inc., Div. of Magnetics Intl., 6001 So. General Ave., Cudahy, Wis. 53110
Stearns-Roger Inc., 700 So. Ash, P.O. Box 5888, Denver, Colo. 80217
Stedman Fdy. & Mach. Co., P.O. Box 209, Aurora, Ind. 47001
Steel Heddle Mfg. Co., Industrial Div., 1801 Rutherford St. (P.O. Box 1867), Greenville, S.C. 29602
Steelplank Corp., 415 Goddard Rd., Wyandotte, Mich. 48192
Stellite Div., Cabot Corp., Kokomo, Ind. 46901
● Stephens-Adamson, Ridgeway Ave., Aurora, Ill. 60507
Sterling Custom Built Trucks, 5000 Mackey, Merriam, Kan. 66203
Sterling Power Systems, Inc., A Sub. of The Lionel Corp., 16752 Armstrong Ave., Irvine, Calif. 92714
Stevens, Inc., C. W., P. O. Box 619, Kennett Sq., Pa. 19348
Stonhard, Inc., Park Ave. & Rte. 73, Maple Shade, N.J. 08052
Stoody Co., Box 1901 CA, Industry, Cal. 91749
Stoody Co. WRAP Div., 11804 Wakeman St., Whittier, Cal. 90607
Straightline Filters Inc., P.O. Box 1911, Wilmington, Del. 19899
Strataflex, Inc., P. O. Box 10398, Ft. Worth, Texas, 76114
Straub Mfg. Co., 8383 Baldwin St., Oakland, Cal. 94621
Streeter Amet, Div. of Mangood Corp., Slusser & Wicks, Grayslake, Ill. 60030
Strojexport, pro, Vaclavske Nam 56, Prag 1, Czechoslovakia
Stromberg-Carlson Corp., P.O. Box 7266, Charlottesville, Va. 22906
Sturtevant Mill Co., 22 Sturtevant St., Dorchester, Boston, Mass. 02122
Sullair Corp., 514 Washington Rd., Pittsburgh, Pa. 15228
Sun Oil Co., 1608 Walnut St., Philadelphia, Pa. 19103
Sundstrand Fluid Handling, Div. Sundstrand Corp., 2480 W. 70th Ave., Denver, Colo. 80221
Super Products Corp., P. O. Box 27225, Milwaukee, Wisc. 53227
Swan Hose Div., P.O. Box 509, Worthington, Ohio, 43085
SWECO Inc., 6033 E. Bandini Blvd., P.O. Box 4151, Los Angeles, Calif. 90051

T

● TBA Industrial Products Ltd., P.O. Box 77, Wigan WN2 4XQ, Lancashire, England
T.J.B Inc., 19940 Ingersoll Dr., Rocky River, Ohio, 44116
T & T Machine Co., Inc., Rte. 8, Box 343, Fairmont, W. Va. 26554

Taber Pump Co., Inc., P. O. Box 1071, Elkhart, Ind. 46514
Tampella-Tamrock, 33310 Tampere 31, Finland
Taylor Instrument Process Control Div. Sybron Corp., 95 Ames St., Rochester, N.Y. 14601
Tazewell Industries, P.O. Box 431, Tazewell, Va. 24651
Teledyne McKay, 850 Grantley Rd., York, Pa. 17405
Teledyne Western Wire & Cable, 2425 E. 30th St., Los Angeles, Calif. 90058
Teledyne Wisconsin Motor, 1910 S. 53rd St., Milwaukee, Wis. 53219
Telsmith Div., Barber-Greene Co., 532 E. Capitol Dr., Milwaukee, Wis., 53212
Templeton, Kenly & Co., 2525 Gardner Rd., Broadview, Ill., 60153
● Terex Div., GMC, Hudson, Ohio, 44236
Terrell Machine Co., Industrial Products Div., P. O. Box 928, Charlotte, N.C., 28201
Texaco Inc., 2100 Hunters Point Ave., Long Island City, N.Y., 11101

Texas Nuclear, 9101 Research Rd (P.O. Box 9267), Austin, Texas 78757
Thayer Scale Hyer Industries, Rt. 139, Pembroke, Mass., 02359
Thermex Metallurgical Inc., Ridgeway Blvd., Lakehurst, N.J. 08733
Thomas Foundries Inc., P.O. Box 96, Birmingham, Ala. 35201
Thor Power Tool Co., 175 N. State St., Aurora, Ill., 60507
Threadaway Bit Corp., 624 N. East Everett, Portland, Ore., 97232
● Thurman Scale Co. Div. Thurman Mfg. Co., 1939 Refugee Rd., Columbus, Ohio, 43215
Tiger Equipment & Services Ltd./O & K Mining Equipment, 222 S. Riverside Plaza, Chicago, Ill. 60606
Timken Co., 1835 Dueber Ave., S.W., Canton, Ohio, 44706
Todd Ent. Inc., 530 Wellington Ave., Cranston, R.I. 02910
Tol-O-Matic, 246 10th Ave., So., Minneapolis, Minn., 55415
Tool Steel Gear & Pinion Co., 211 Township Ave., Cincinnati, Ohio, 45216
Torit Div. Donaldson Co. Inc., P.O. Box 3217, St. Paul, Minn., 55165
Torrington Co., The Bearings Div., 3702 W. Sample St., South Bend, Ind., 46634
TOTCO Div. Baker Oil Tools, Inc., 506 Paula Ave., Glendale, Calif. 91201
Toyo Tire (USA) Corp., 3136 E. Victoria St., Compton, Cal., 90221
Trabon Lubricating Systems, Div. of Houdaille Industries, Inc., 28815 Aurora Rd., Solon, Ohio, 44139
Tracy, Bertrand P. Co., 919 Fulton St., Pittsburgh, Pa., 15233
Tread Corp., Box 5497, Roanoke, Va. 24012
Treadwell Corp., 1700 Broadway, New York, N.Y. 10019
● Trelleborg Rubber Co., Inc., 30700 Solon Ind. Pkw., Solon, OH, 44139
Triangle/PWC, Inc., A Sub. of Triangle Industries, Inc., Box 711, Triangle & Jersey Aves., New Brunswick, N.J. 08903
Trico Mfg. Corp., 2948 N. 5th St., Milwaukee, Wis., 53212
Tricon Metals & Services, Inc., P.O. Box 6634, Birmingham, Ala., 35210
Trojan Div. IMC Chemical Group, Inc., 17 N. 7th St., Allentown, Pa., 18105
Trowelon, Inc., 973 Haven Dr., P.O. Box 3126, Green Bay, Wis., 54303
TRW Mission Mfg. Co., Div. of TRW Inc., P.O. Box 40402, Houston, Texas, 77040
● Tube-Lok Products Div. of Portland Wire & Iron, 4644 S.E. 17th Ave., Portland, Ore., 97202
Tube Turns Div., Chemetron Piping Systems, 2900 W. Broadway, Louisville, Ky., 40201
TWECO Products, Inc., P. O. Box 666, Wichita, Kan., 67201
Twin Disc, Inc., 1328 Racine St., Racine, Wis., 53403
Twisto-Wire Fire Systems, Inc., 302 E. Huntington Dr., Arcadia, Calif., 91006

U

Underground Mining Machinery Ltd., P.O. Box 19, Aycliffe Industrial Estate, Darlington, Co. Durham DL5 6DS, England
Uniflex Limited, 11/16 Adelaide St., Swansea, U.K.
Unitak Belting Co., Div. of Georgia Duck and Cordage Mill, Scottdale, Ga., 30079
Union Carbide Corp., 270 Park Ave., New York, N.Y., 10017
● Union Oil Co. of California, 200 E. Golf Rd., Palatine, Ill. 60067
Union Forge, Inc., Stop St., Noblestown, Pa. 15070
Unique Products Co., 12867 Mac Neil St., Sylmar, Calif. 91342
Uniroyal, Inc., 1230 Ave. of Americas, New York, N.Y. 10020
Unit Crane & Shovel Corp., 1915 South Moorland Rd., New Berlin, Wis. 53151
United McGill Corp., 2400 Fairwood Ave., Columbus, Ohio, 43216
U.S. Electrical Motors Div. Emerson Electric Co., 125 Old Gate Lane, Milford, Conn., 06460
U.S. Gypsum Co., 101 S. Wacker Dr., Chicago, Ill., 60606
U.S. Polymeric, Sub. of Armco Steel Corp., 700 E. Dyer Rd., Santa Ana, Cal., 92707
United States Steel Corp., 600 Grant St. - Rm. 2106, Pittsburgh, Pa., 15230
United Tire & Rubber Co., Ltd., 275 Belfield Rd., Rexdale, Ont., Canada, M9W5C6
Uni-Tool Attachments, Inc., 1607 Woodland Ave., Columbus, Ohio, 43219
Universal Atlas Cement Co., 600 Grant St., 12th Fl., Pittsburgh, Pa., 15230
● Universal Industries, P. O. Box 98, 245 S. Washington, Hudson, Iowa, 50643
Universal Road Machinery Co., 27 Emerick St., Kingston, N.Y., 12401
Universal Vibrating Screen Co., P. O. Box 1097, 1745 Deane Blvd., Racine, Wis., 53405

V

VME Nitro Consult Inc., 1737 Central St., Evanston, Ill. 60201
Valley Steel Products Co., P.O. Box 503, St. Louis, Mo., 63166
Van Gorp Mfg. Inc., Box 123, Pella, Iowa, 50219
Varel Mfg. Co., Inc., 9230 Denton Dr., P. O. Box 20156, Dallas, Texas, 75220
Varian Associates, 611 Hansen Way, Palo Alto, Calif., 94303
Vehicle Constructors Div., Marion Power Shovel Co., 7336 Air Freight Lane, Dallas, Tex., 75235
Vibco Inc., P.O. Box 8, Stilson Rd., Wyoming, R.I. 02898
Vibranetics, Inc., 2714 Crittenden Dr., Louisville, Ky., 40209
● Vibra Screw Inc., 755 Union Blvd., Totowa, N.J. 07512
● Victaulic Co. of America, 3100 J Hamilton Blvd., So. Plainfield, N.J. 07080
Victor Products (Wallsend) Ltd., P. O. Box Wallsend, Tyne and Wear NE28 6PP, England
Viking Oil & Machinery Co., Rt. 8, Orebank Rd., Kingsport, Tenn., 37664
Vortex Air Corp., P.O. Box 928, Beckley, W. Va., 25801
● VR/Wesson, a Div. of Fansteel, 800 Market St., Waukegan, Ill., 60085
Vulcan Materials Co., Southeast Div., P.O. Box 7324 A, Birmingham, Ala., 35223

W

● WABCO Construction and Mining Equipment Group, an American Standard Co., 2300 N.E. Adams St., Peoria, Ill. 61639
WABCO Fluid Power Div., an American Standard Co., 1953 Mercer Rd., Lexington, Ky. 40505
WABCO Union Switch & Signal Div., Westinghouse Air Brake Co., an American Standard Co., Pittsburgh, Pa. 15218
Wachs, E. H. Co., 100 Shepard St., Wheeling, Ill., 60090
Wagner Mining Equip., P. O. Box 20307, Portland, Ore. 97220
Wajax Industries Ltd., 350 Sparks St., Ste. 1105, Ottawa, Ont., Canada, K1G 3G8
Walco Industries, Inc., N.W. Cor. Race & Camac Sts., Philadelphia, Pa., 19107
● Waldon Inc., Fairview, Okla., 73737
Walker Parkersburg Textron, 620 Depot St., Parkersburg, W. Va., 26101
Wall Colmonoy, 19345 John R St., Detroit, Mich., 48203
Wallacetown Engineering Co. Ltd., Heathfield Rd., Ayr KA89 SR, England
Walter Nold Co., 24 Birch Rd., Natick, Mass., 01760
Ward Hydraulics Div., ATO Corp., 11980 Walden Ave., Alden, N.Y., 14004
Warman International, Inc., 2701 S. Stoughton Rd., Madison, Wis., 53716

About the Buying Directory . . .

This 1976 edition of the Coal Age Buying Directory remains the most complete directory of equipment, supplies, and services available to the coal mining industry.

For several years, the entire directory has been stored in a computer data bank. Early each year, a computerized questionnaire is printed for each listed manufacturer, showing the categories under which his products appeared in the preceding edition of the Buying Directory.

Each manufacturer is asked to revise the listing where necessary, adding any new products or services available to the coal mining industry.

The information supplied by manufacturers is then used to update the computerized listing and is stored in the data bank.

Warn Industries, 19450 68th Ave. So., Kent, Wash., 98031
Warner & Swasey, Construction Equipment, Solon, Ohio, 44139
Warren Rupp Co., The, 800 N. Main, P.O. Box 1568, Mansfield, Ohio, 44901
Watt Car & Wheel Co., Box 71, Barnesville, Ohio, 43713
Waukesha Engine Div., 1000 St. Paul Ave., Waukesha, Wis., 53186
● Weatherhead Co., The, 300 E. 131st St., Cleveland, Ohio 44108
Webb, Jervis B., Co., 9000 Alpine Ave., Detroit, Mich., 48204
Webster Mfg. Co., W. Hall St., Tiffin, Ohio, 44883
● Wedge Wire Corp., P. O. Box 157, Wellington, Ohio, 44090
Weir, Paul Co., Inc., 20 N. Wacker Dr., Chicago, Ill., 60606
Wellman, S.K., Corp., The, 200 Egbert Rd., Bedford, Ohio, 44146
Wells Cargo Inc., P.O. Box 7128-CA, Waco, Tex., 76710
Welsh Div. of Textron, 2000 Plainfield Pike, Cranston, R.I., 02920
WEMCO Div., Envirotech Corp., P.O. Box 15619, Sacramento, Calif., 95813
Wen-Don Corp., P.O. Box 12094, Roanoke, Va., 24022
Wescott Steel Inc., 1020 Washington Ave., Croydon, Pa., 19020
WESMAR Level Monitor Div., 905 Dexter Ave. N., Box C19074, Seattle, Wash., 98109
West Virginia Armature Co., P. O. Box 1100, Bluefield, W. Va., 24701
West Virginia Belt Sales & Repairs Inc., P. O. Box 32, Mount Hope, W. Va., 25880
Western Precipitation Div., Joy Mfg. Co., P. O. Box 2744, Terminal Annex, Los Angeles, Calif., 90051
Westfalia Lunen, D 4670 Lunen, P.O. Box, Germany
Westinghouse Electric Corp., Westinghouse Bldg., Gateway Center, Pittsburgh, Pa., 15222
Westlake Plastics Co., Lenni Rd., Lenni, Pa., 19052
Wheelabrator-Frye Inc., Air Pollution Control Div., 600 Grant St., Pittsburgh, Pa., 15219
Wheelabrator-Frye, Inc., Materials Cleaning Systems, 1476 S. Byrkit St., Mishawaka, Ind., 46544
White Engines, Inc., 101 - 11th St. S.E., Canton, Ohio, 44707
White Motor Corp. Truck Group, 35129 Curtis Blvd., Eastlake, Ohio, 44094
White Superior Div., White Motor Corp., 1401 Sheridan Ave., Springfield, Ohio, 45505
Whiting Corp., 15700 Lathrop, Harvey, Ill., 60426
Whitmore Mfg. Co., The, P. O. Box 488, Cleveland, Ohio, 44127
Whittaker Corp., 10880 Wilshire Blvd., Los Angeles, Calif., 90024
Wichita Clutch Co., Inc., 307 Barwise St., (P.O. Box 1550), Wichita Falls, Texas, 76307
● Wiegand, Edwin L., Div., Emerson Elec. Co., 7867 Thomas Blvd., Pittsburgh, Pa., 15208
Wiggins Connectors Div. Delaval Turbine Inc., 5000 Triggs St., Los Angeles, Calif., 90022
Wild Heerbrugg Insts. Inc., 465 Smith St., Farmingdale, N.Y., 11735
● Wilfley, A. R., & Sons, P. O. Box 2330, Denver, Colo., 80201
Williams, J. H. Div. of TRW Inc., 400 Vulcan St., Buffalo, N.Y., 14207

Williams Patent Crusher & Pulv. Co., 810 Montgomery St., St. Louis, Mo., 63102
Willis & Paul Corp., The, 125-135 Main St., Netcong, N.J., 07857
Wilson Engineering Co., 2101 Pleasant Valley Rd., Fairmont, W. Va., 26554
Willson Products Div., ESB, Inc., P. O. Box 622, Reading, Pa., 19603
Wilmot Engineering Co., Berwick St., White Haven, Pa., 18661
● Wilson, R. M., Co., Box 6274, Wheeling, W. Va., 26003
Wing Co., The, Div. of Aero-Flow Dynamics, Inc., 2300 N. Stiles St., Linden, N.J., 07036
Winslow Scale Co., P.O. Box 1523, Terre Haute, Ind., 47808
Wire Cloth Enterprises, Inc., RIDC Industrial Park, Pittsburgh, Pa., 15238
Wire Rope Corp. of America, Box 288, St. Joseph, Mo., 64502
Wood's, T. B., Sons Co., 440 N. Fifth Ave., Chambersburg, Pa., 17201
Workman Developments, Inc., 1741 Woodvale Rd., Charleston, W. Va., 25314
● Worthington Pump Inc., 270 Sheffield St., Mountainside, N.J., 07092

Y

Yardney Electric Corp., 82 Mechanic St., Pawcatuck, Conn., 02891
Yaun Williams Bucket Co., 10100 Brecksville Rd., Brecksville, Ohio, 44141
● Young Corp., Box 3522, Seattle, Wash., 98124
Youngstown Sheet & Tube Co., The, Post Office Box 900, Youngstown, Ohio, 44501

Z

Zeni Drilling Co., 324 Eighth St., Morgantown, W. Va., 26505

APPENDIX IX

English - Metric Conversion Charts

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CONVERSION FACTORS FOR BRITISH AND METRIC UNITS

To convert from	To	Multiply by	To	Multiply by
^{o}F	^{o}C	$\frac{5}{9}$ (°F-32)	- - - - -	- - - - -
ft.	meters	0.305	centimeters	30.5
$ft.^{2}$	$meters^{2}$	0.0929	$centimeters^{2}$	929.0
$ft.^{3}$	$meters^{3}$	0.0283	$centimeters^{3}$	28,300.0
ft./min. (fpm)	centimeters/sec.	0.508	meters/sec.	5.08×10^{-3}
$ft.^{3}/min.$	$centimeters^{3}/sec.$	471.9	$meters^{3}/hr.$	1.70
in.	centimeters	2.54	meters	2.54×10^{-2}
$in.^{2}$	$centimeters^{2}$	6.45	$meters^{2}$	6.45×10^{-4}
oz.	grams	28.34	grains	438.0
$oz./yd.^{2}$	grams $meter^{2}$	33.89	$grams/centimeter^{2}$	3.39×10^{-3}
grains	grams	0.0647	- - - - -	- - - - -
$grains/ft.^{2}$	grams $meter^{2}$		- - - - -	- - - - -
$grains/ft.^{3}$	$grams/meter^{3}$	2.288	- - - - -	- - - - -
lb. force	dynes	4.44×10^{5}	newtons	0.44
$lb./ft.^{2}$	$grams/centimeter^{2}$	0.488	$grams/meter^{2}$	4,880.0
in. H_2O/ft./min.	cm. H_2O/cm/sec.	5.00	$Newtons/meter^{2}/cm/sec.$	490.0
Btu	calories	252	- - - - -	- - - - -

BEST SELLERS

FROM NATIONAL TECHNICAL INFORMATION SERVICE

NTIS

State Implementation Plan Emission Regulations for Sulfur Oxides: Fuel Combustion
PB-251 174/PAT 82 p PC$5.00/MF$3.00

Compilation of Air Pollutant Emission Factors. Supplement No. 6
PB-254 274/PAT 59 p PC$4.50/MF$3.00

Energy-Economy Relationships
PB-255 171/PAT 313 p PC$9.75/MF$3.00

Environmental Impacts of Virgin and Recycled Steel and Aluminum
PB-253 487/PAT 124 p PC$5.50/MF$3.00

Final Generic Environmental Statement on the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors—Health, Safety and Environment. Executive Summary
PB-256 487/PAT 33 p PC$4.00/MF$3.00

Regional Comparison of Savings from Various Residential Energy Conservation Strategies
ORNL-TM-5146/PAT 70 p PC$4.50/MF$3.00

Residential Hot Water Solar Energy Storage Subsystems
PB-252 685/PAT 117 p PC$5.50/MF$3.00

Directory of Federal Energy Data Sources. Computer Products and Recurring Publications
PB-254 163/PAT 84 p PC$5.00/MF$3.00

Quality Assurance Handbook for Air Pollution Measurement Systems. Volume I. Principles
PB-254 658/PAT 379 p PC$10.75/MF$3.00

Uranium Reserves, Resources, and Production
PB-254 896/PAT 18 p PC$3.50/MF$3.00

National Petroleum Product Supply and Demand, 1976-1978
PB-254 969/PAT 249 p PC$8.00/MF$3.00

Scientific and Technical Data Base for Criteria and Hazardous Pollutants—1975 ERC/RTP Review
PB-253 942/PAT 464 p PC$12.00/MF$3.00

Markets and Technology for Recovering Energy from Solid Waste
PB-253 326/PAT 37 p PC$4.00/MF$3.00

Evaluation of Pollution Control in Fossil Fuel Conversion Processes
PB-255 842/PAT 306 p PC$9.75/MF$3.00

Common Environmental Terms. A Glossary
PB-254 630/PAT 25 p PC$3.50/MF$3.00

Availability of Conventional Energy Resources Materials—Coal
PB-255 798/PAT 17 p PC$3.50/MF$3.00

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- ☐ Purchase order no. ____________
- ☐ Check enclosed for $____________
- ☐ Bill me. Add $5.00 per order and sign below. (Not available outside North American continent.)
- ☐ Charge to my American Express Card account number

☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

Card expiration date ____________

Signature ____________

☐ Airmail Services requested

NAME ____________

ADDRESS ____________

CITY, STATE, ZIP ____________

Clip and mail to:

NTIS

National Technical Information Service
U.S. DEPARTMENT OF COMMERCE
Springfield, Va. 22161
(703) 557-4650 TELEX 89-9405

Item Number	Quantity		Unit Price*	Total Price
	Paper Copy (PC)	Microfiche (MF)		

Sub Total	
Additional Charge	
Enter Grand Total	

All prices subject to change. The prices above are accurate as of 2/77.

Foreign Prices on Request.